













# **107 Stories about Chemistry**

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A hundred years or so ago a scientist had the idea of writing a book to describe all the discoveries and advances of chemistry and the properties of all the compounds then known. But even a hundred years ago chemistry was progressing so rapidly that the would-be author felt an urge to appeal to his colleagues to stop their research for at least a year. Otherwise he simply wouldn't be able to keep abreast of all the new facts and theories.

What would be his predicament today, with chemistry's horizons literally boundless as they are now?

The authors of this book have endeavoured to touch upon the most important and interesting problems of chemistry.

Their book describes and explains the structure of the Periodic System of Elements;

it guides you through a kind of chemical museum full of curious exhibits;

it tells of the intricate substances chemists have produced and how they have learned to work even with single atoms of the elements;

it acquaints you with the various chemical professions and shows how chemistry has penetrated all spheres of human activity.

We hope reading these short but instructive stories about the exciting discoveries of chemistry will urge you to find out more about this fascinating science and to take up chemistry seriously.



## **Instead of a Preface**

Once upon a time there was a very wise and learned ruler in the East who wished to know all about the peoples that inhabited the Earth.

He summoned his viziers and commanded:

"Write me a history of all the nations in the world, and tell me how they lived before and how they live now, what they do, what wars they have fought and are waging now, and what trades and arts flourish in different countries."

And he gave them five years to do this.

The viziers bowed in silence. Then they called together the wisest of the wise men in the kingdom and announced their ruler's will to them. It is said this caused an unprecedented boom in the parchment industry.

Five years later the viziers reassembled at the palace.

"Your will is done, O great king! Look out the window and you will see that which you have desired..."

The ruler rubbed his eyes in amazement. Before the palace stood a caravan of camels, so long that the end was lost beyond the horizon. Each camel carried two huge packs and in each pack were ten enormous volumes beautifully bound in Morocco.

"What is that?" asked the monarch.

"It is a history of the world," replied the viziers. "At your command the wisest of the wise have toiled at it incessantly for five years!"

"Would you make fun of me?" thundered the monarch. "I could not read a tenth of what they have written by the end of my life! Let them

write me a short history. But let it include all the important events."

And he gave them another year.

The year passed and again a caravan stood before the palace. It was now only ten camels long, each camel carrying two packs of ten volumes on its back

The monarch was furious

"Let them write only of the most important events that happened among all nations in all times How long will that take?"

Then the wisest of all the wise men came forward and said:

"Tomorrow, my Lord, you will have what you desire!"

"Tomorrow?" echoed the ruler in surprise. "Very well. But if you are deceiving me you shall lose your head!"

...Hardly had the sun mounted the blue sky and the slumbering flowers opened in all their splendour, than the monarch had the wise man summoned.

The sage entered with a tiny sandal-wood box in his hands.

"You will find here, O great king, the most important events that ever happened in the history of all the peoples in all times," said the sage with a low bow.

The monarch opened the box. On a velvet cushion lay a small slip of parchment with a single phrase written on it: "They were born, they lived, and they died."

So runs the old legend. And when we were asked to write an entertaining book about chemistry and were told that paper would be limited

(meaning the size of the book, of course) we could not help remembering it. That meant we could only write about the most important things. But what *are* the most important things in chemistry?

"Chemistry is the science of substances and their transformations."

Can you blame us for recalling that scrap of parchment in the sandal-wood box?

We scratched our heads, and racked our brains and decided that everything in chemistry is important. One thing may seem more important to one person and less important to another. For instance, an inorganic chemist may consider inorganic chemistry the hub of the universe, but an organic chemist would be of quite the opposite opinion. There is no soothing uniformity of views on this point.

Civilization is the sum of numerous items, and one of the most important of them is chemistry.

Chemistry enables man to smelt metals from ores and minerals. Without chemistry modern metallurgy would be impossible.

Chemistry makes more and more wonderful substances from animal and vegetable and mineral materials.

It does not simply copy nature or imitate it, but surpasses it in more and more different ways year by year. Thousands and thousands of substances have been produced that are not found in nature but possess very important and useful properties of great utility for the life and work of man.

The list of chemistry's good deeds is practically inexhaustible.



Every aspect of life involves an immense number of chemical processes. It is impossible to understand the fundamentals of vital activities without knowledge of the laws of chemistry.

Chemistry has had its say in the evolution of man.

Chemistry feeds us, clothes us, shoes us, and gives us the things without which modern civilized society cannot function.

The first rockets have been fired into outer space. Chemistry provided the fuel for their motors and strong heat-resistant materials for their design.

Should anyone try to write everything about chemistry in all its innumerable aspects and in all its splendour, the paper resources of even a highly developed state would be threatened with exhaustion. Fortunately, the idea has not yet occurred to anyone; but the task before us was one of a similar nature.

We found a way out of our dilemma. We decided to write a little about a lot of different things. Of course, what to write about is rather a matter of taste. Other writers would probably have told about other things, and others still about still other things. But this is *our* book, the way we wrote it; so if you do not happen to find in it exactly what you wanted to know, please don't be annoyed with us.

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# **The Inhabitants of the Big House**



## **A Bird's-Eye View of the Periodic System**

A fleeting glance, a first impression, is usually of little value. Sometimes it leaves the observer indifferent, sometimes it surprises him. Once in while it makes him exclaim, like the hero of the well known anecdote when he saw the giraffe at the Zoo: "It can't be true!"

But even a first acquaintance with a thing or a phenomenon, a bird's-eye view of it, if you like, is often useful.

Mendeleyev's Periodic System of Elements can hardly be called a thing or a phenomenon. It is rather a kind of mirror reflecting the essentials of one of the greatest laws of nature, the Periodic Law. This is a code of behaviour obeyed by the hundred odd elements found on Earth or produced artificially by man, a set of regulations, as it were, prevailing in the Big House of the chemical elements. . . .

A first glance at this house reveals a great deal. The first feeling is one of surprise, as if in the midst of standard large-panel buildings we suddenly saw a house of whimsical but elegant architecture.

What is it that is surprising about Mendeleyev's Table? To begin with, the fact that its periods, its storeys, have different floor plans.

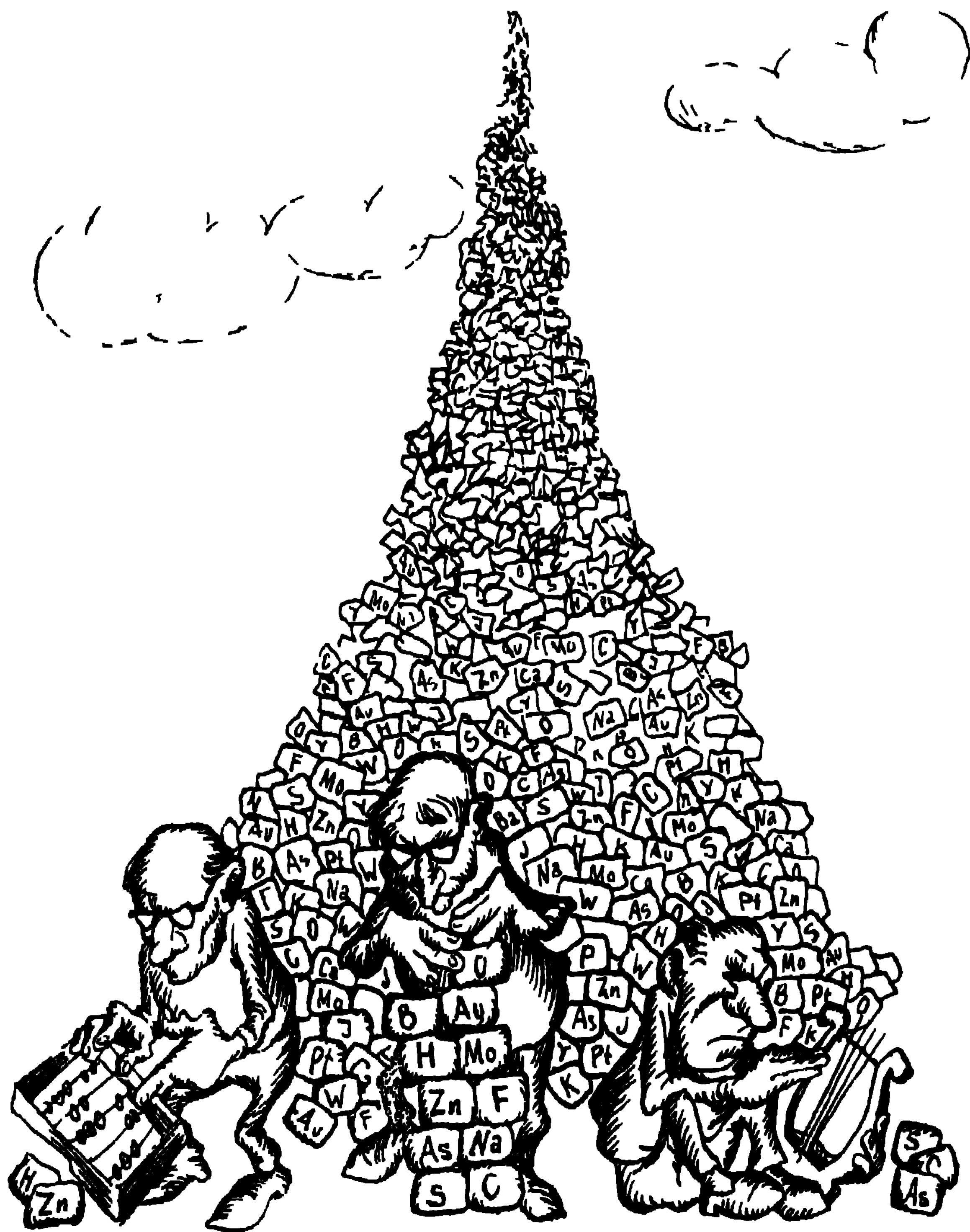
The first storey\* or first period of the Mendeleyev Table, has only two rooms or boxes. The

\* Unlike ordinary houses, the "storeys" of Mendeleyev's Big House (Periodic System) should be numbered from top to bottom, because any new "storey" that might have to be added to accommodate new elements would have to be attached to the bottom of the table.



second and third have eight each. The next two storeys (the fourth and fifth) have eighteen rooms each, like in a hotel. The two below that (the sixth and seventh) have even more rooms, thirty-two each. Have you ever seen such a building?

Still that is the form of the Big House of chemical elements known as the Periodic System.



Architector's whim? Not at all! Any building has to be designed in accordance with the laws of physics; otherwise the least breath of wind will topple it over.

The physical laws that underly the architecture of the Periodic System are just as strict and decree that each period of the Mendeleev Table shall contain a definite number of elements. For instance, the first period has two elements, no more and no less.

That is what the physicists affirm and the chemists fully agree with them.

But they didn't always agree. There was a time when the physicists said nothing, because the Periodic Law had not yet begun to bother them. But the chemists who were discovering new elements almost every year were finding it harder and harder to know where to put the newcomers. And there were annoying situations when there was a whole queue of claimants for the same box in the table.

Not a few scientists were sceptical. They declared quite soberly that the edifice of Mendeleev's Table was built on sand. One of these was the German chemist Bunsen, who developed the method of spectroscopic analysis together with his friend Kirchhoff. But when it came to the Periodic Law Bunsen exhibited surprising scientific shortsightedness. "One might just as well seek regularities in the figures of stock exchange bulletins!" he snapped out once in a fit of anger.

There had been attempts before Mendeleev's to put the sixty-odd chemical elements then known into some kind of order. But they were

not successful. The Englishman Newlands probably came the closest to the truth. He suggested a "Law of Octaves." On arranging the elements in order of increasing atomic weight Newlands found that as in music where each eighth note repeats the first at a higher level, the properties of every eighth element resembled those of the first. But the reaction Newlands' discovery evoked was: "Why don't you try arranging the elements in alphabetical order? You might detect some regularity that way too!"

What could poor Newlands reply to his sarcastic opponent? Mendeleev's Table was not particularly lucky at first. Its "architecture" came under furious attack. For much in it remained obscure and required explanation. It was easier to discover half-a-dozen new elements than to find proper positions for them in the table.

Only on the first floor did things seem satisfactory. There was no danger of an unexpected flow of lodgers here. This floor is inhabited now by hydrogen and helium. The nuclear charge of the hydrogen atom is  $+1$ , and that of the helium atom  $+2$ . There clearly are not and cannot be any other elements between them. There are no nuclei or other particles in nature that we know of, whose charges are fractional numbers.

(Recently, however, theoretical physicists have persistently been discussing the question of the existence of quarks. This is the name given to primary elementary particles from which all the rest can be built, including protons and neutrons, the component parts of atomic nuclei. Quarks are assumed to have fractional electric charges:  $+1/3$

and  $-1/3$ . If quarks actually exist, the "material arrangement" of the universe may appear in a new light.)

### **How the Astronomers Sent the Chemists on a Wild Goose Chase**

"It never occurred to me that the Periodic System should begin precisely with hydrogen."

Whose words do you think these are? They would be most likely to come from one of the legion of investigators or amateurs who set themselves the task of drawing up a new periodic system all of their own or of rearranging it to suit themselves. The diversity of "periodic systems" that made their appearance was no smaller than of notorious perpetual motion machine projects.

Well, the phrase in quotation marks was written by none other than D. Mendeleev. It appeared in his famous "Foundations of Chemistry," a textbook used in its time by tens of thousands of students.

Now why was the author of the Periodic Law mistaken?

In his time there were all grounds for such mistakes. The elements were then arranged in the Table in order of increasing atomic weight. The atomic weight of hydrogen is 1.008, of helium—4.003. Hence, why not assume that there might be elements with atomic weights of 1.5, 2, 3, and so on? Or elements lighter than hydrogen, with atomic weights smaller than unity?

Mendeleev and many other chemists thought this to be quite possible. And they were supported by the astronomers, representatives of a scien-

ce very far removed from chemistry. We daresay, their support was involuntary. It was the astronomers that first proved new elements to be discoverable not only in the laboratory and not only by analysing terrestrial minerals.

In studying the total solar eclipse of 1868 the English astronomer Lockyer and the French astronomer Janssen passed the blinding light of the solar corona through a spectroscopic prism. In the dense palisade of spectral lines they observed some that could belong to none of the elements known on Earth. Thus was discovered helium, the name coming from the Greek for "solar." Only twenty-seven years later did the English physicist and chemist William Crookes discover helium on Earth.

His discovery proved contagious. Astronomers began to point their telescopes at distant stars and nebulae. Their findings were scrupulously published in astronomical yearbooks, and some even found their way into chemical journals. These were findings which treated of alleged discoveries of new elements in the boundless space of the universe. The elements were given pompous names such as coronium and nebulium, archonium and protofluorine. Apart from their names, chemists knew nothing about them. But bearing in mind the happy end of the helium story, they hurried to place these celestial strangers in the Periodic System. They put them before hydrogen or in the space between hydrogen and helium. And they cherished the hope that at some time in the future new Crookeses would prove coronium and its no less mysterious fellows to exist on Earth.

But as soon as the physicists tackled the Periodic System these hopes were shattered. Atomic weights were found to be an unreliable footing for the Periodic Law. They were replaced in this function by the nuclear charge, or the atomic number of the element.

In passing from element to element in the Periodic System this charge increases by one unit each time.

Time passed and more precise astronomic instruments scattered the myth of the mysterious nebulae. They turned out to be atoms of long known elements, atoms that had lost some of their electrons and therefore gave unfamiliar spectra. The "business cards" of the celestial strangers proved false.

### **A Two-Faced Element**

You may have heard a dialogue something like this during a chemistry lesson at school.

Teacher:

"What group of the Periodic System is hydrogen in?"

Pupil:

"In the first. This is so because like the other elements of the first group, the alkali metals lithium, sodium, potassium, rubidium, cesium, and francium, the hydrogen atom has only one electron in its only electron shell. Like them, hydrogen displays a positive valence of one in chemical compounds. Finally, hydrogen is capable of displacing some metals from their salts."

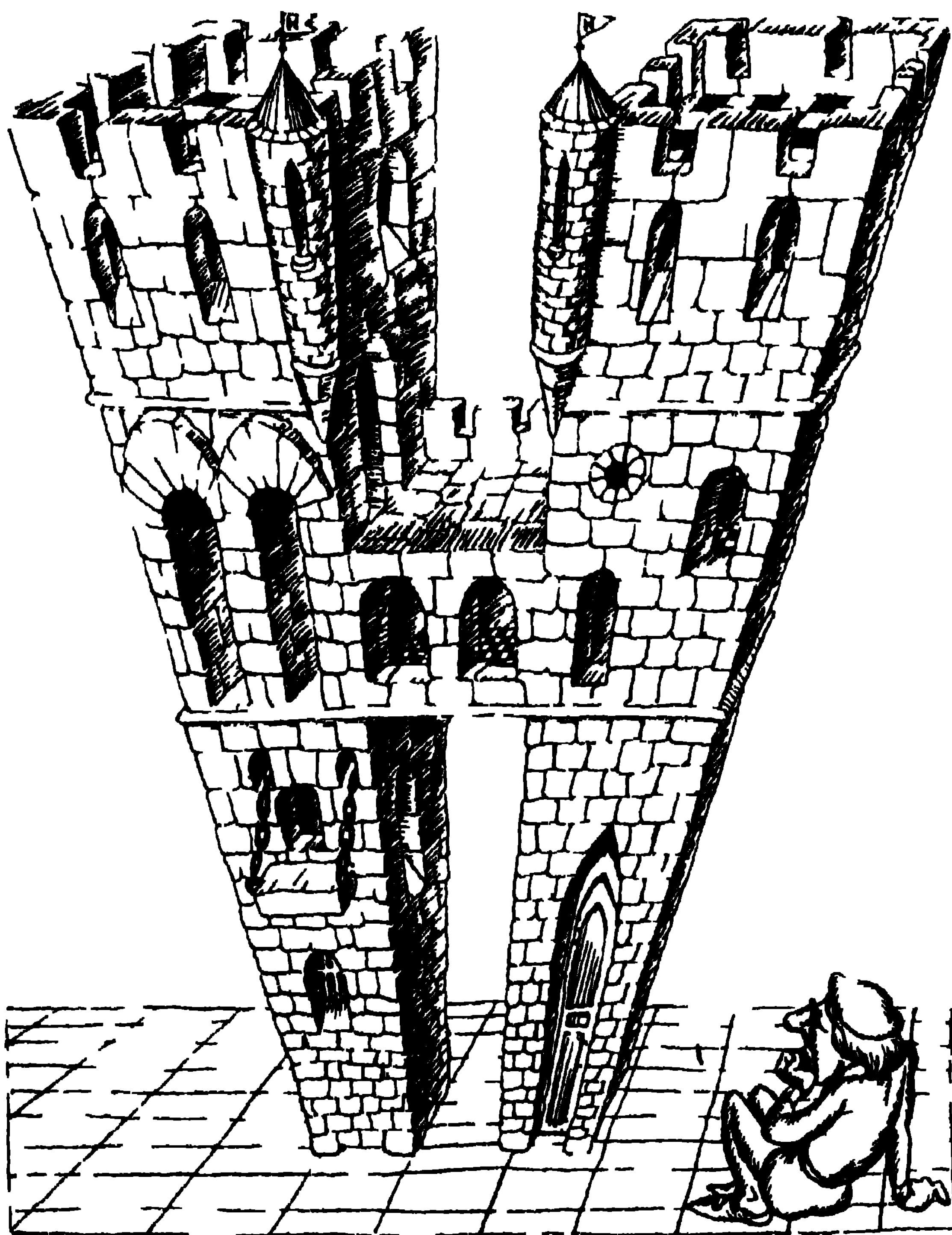
Is this true? Yes, but only half true...

Chemistry is a precise science and chemists do



not like half truths Hydrogen is a convincing example

What is there in common between hydrogen and the alkali metals? Only their positive valence of 1 Only the similar arrangement of their outer electron shells As to the rest, they bear



no resemblance at all. Hydrogen is a gas and a nonmetal. Hydrogen forms a diatomic molecule. The rest of the elements of the first group are classical metals, and the most active ones as far as chemical reactions go. Brandishing its only electron, hydrogen tries to don the toga of an alkali metal. But actually it is a wolf in sheep's clothing.

The Big House is so arranged that kindred elements live one above the other off each stair well, comprising the groups and subgroups of the Periodic System. This is the law for the inhabitants of the Big House. By falling into Group I, hydrogen inevitably breaks this law.

But where is poor hydrogen to go? There are all in all nine groups, nine stair wells in the Big House. Helium, hydrogen's first-floor neighbour, found its flat only in what is now called the zero group. The places in the rest of the groups are vacant. See how many possibilities there are for replanning the first floor to find hydrogen a real "place under the sun!"

Couldn't it be lodged in the second group, with the alkaline-earth metals headed by beryllium? No, they feel absolutely no kinship towards hydrogen. The third, fourth, fifth and sixth groups also refuse to have anything to do with it. What about the seventh group? Wait! The halogens occupying this group, fluorine, chlorine, bromine, etc., are ready to extend a friendly hand to hydrogen.

...Imagine a meeting between two children.

"How old are you?"

"So much."

"So am I."



"I've got a bicycle!"

"Me too!"

"What's your Dad?"

"A truck driver!"

"Whce—! So is mine!"

"Let's be friends?"

"Let's!"

"Are you a nonmetal?", fluorine asks hydrogen.

"Yes!"

"Are you a gas?"

"That's right."

"So are we," says fluorine, nodding at chlorine.

"My molecule consists of two atoms!" contributes hydrogen.

"Well, what do you know about that!" says fluorine in surprise. "Just like ours."

"And can you show negative valence, accept additional electrons? We are awfully fond of doing that!"

"Of course I can. I form hydrogen compounds known as hydrides with the very alkali metals that dislike me so, and my valence in them is minus one."

"All right then, pitch right in with us and let's be friends!"

And hydrogen takes up its abode in the seventh group. But not for long. After getting to know its new relation a little better one of the halogens remarks disappointedly:

"See here, brother. You don't seem to have many electrons on your outer shell, do you? Only one, as a matter of fact... Like them blokes in group one. Hadn't you better get back to the alkali metals?"

See what difficult straits hydrogen is in: there are plenty of rooms but none it can occupy permanently, with full rights.

But why? What is the reason for this surprising tow-facedness of hydrogen? What makes hydrogen behave so eccentrically?

The specific properties of any chemical element become evident when it combines with other elements. It then yields or accepts electrons which either leave its outer shell or enter it. When an element loses all the electrons of its outer shell, the rest of its shells usually remain unchanged. Such is the case with all the elements except hydrogen. When hydrogen parts with its only electron, all that remains is its atomic nucleus. What is left is a proton, this being, as a matter of fact, all the hydrogen atom nucleus consists of (actually it does not always consists of only a proton, but we shall come to this important point later). Hence the chemistry of hydrogen is the only chemistry of its kind, as it were, the chemistry of an elementary particle, the proton. Thus, reactions involving hydrogen proceed under the influence of protons.

And that is why hydrogen behaves so inconsistently.

### **The First and the Most Surprising**

Hydrogen was discovered by the famous English physicist the Hon. Henry Cavendish. He was the richest of the learned and the most learned of the rich, as one of his contemporaries put it. We might add that he was the most punctilious of scientists. It is said that whenever Caven-

dish borrowed a book from his own library he always signed his name on the book card. The most sedate of scientists, devoted entirely to scientific research, always engrossed in his science, he got the reputation of an eccentric recluse. But it was just these qualities that enabled him to discover the new gas hydrogen. And, believe us, it was no easy task!

He made his discovery in 1766; and by 1783 the French Professor Charles had flown the first hydrogen-filled balloon

Hydrogen was a most valuable find to chemists, too. It helped them to get an insight into the structure of acids and bases, these most important classes of chemical compounds. It became an indispensable laboratory reagent for precipitating metals from solutions of salts, and for reducing metallic oxides. And paradoxical though it seems, had hydrogen not been discovered in 1766, but, say, half a century later (such a thing could really have happened) the progress of chemistry, both in theory and practice, would have been retarded for a long time.

When the chemists had come to know hydrogen well enough, and practical workers had begun to utilize it for the production of important substances, this gas drew the attention of physicists. And they found out a great deal of information which enriched science many times over.

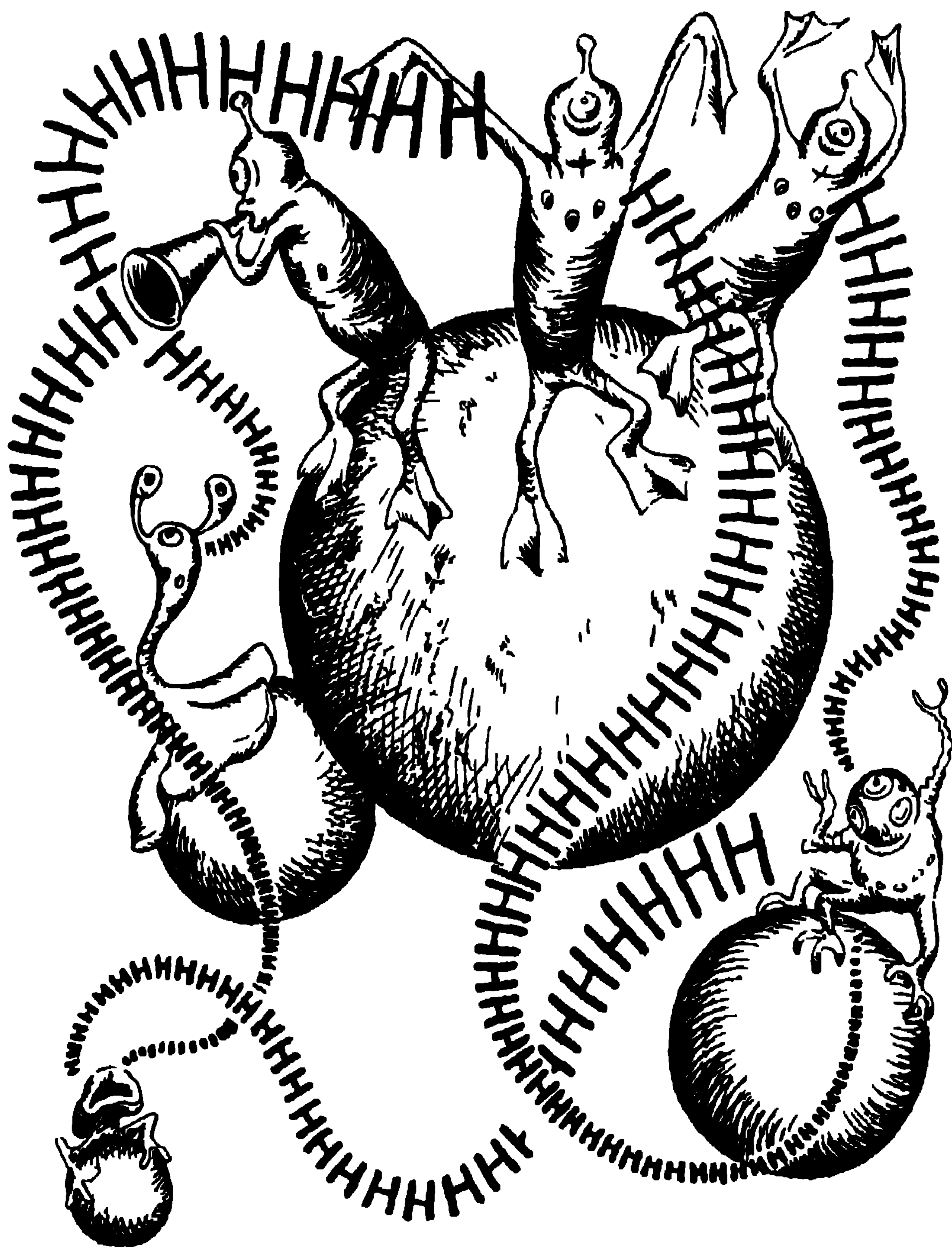
Do you need more evidence? For one thing, hydrogen solidifies at a lower temperature than any other liquid or gas (except helium), at minus  $253^{\circ}$  Celsius. Secondly, the hydrogen atom groled the Danish physicist Niels Bohr to work ka/a theory of the arrangement of electrons

around the atomic nucleus, without which the physical sense of the Periodic Law could not have been understood. And these facts laid the foundation for other very important discoveries.

Then the physicists passed the baton on to their close relatives by profession, to the astrophysicists who studied the composition and structure of the stars. The astrophysicists stated that hydrogen is element Number One in the universe. It is the main component of the Sun, the stars, nebulae, and the basic "filler" of interstellar space. There is more hydrogen in outer space than all the other chemical elements taken together. Nothing like on Earth, where its content amounts to less than one per cent.

Scientists consider hydrogen the starting point of the long train of transformations of atomic nuclei, the train which resulted in the formation





of all the chemical elements, of all atoms without exception. Our Sun and all the stars are luminous because of the thermonuclear reactions occurring in them, involving the transformation of hydrogen into helium with the release of enormous amounts of energy. A prominent chemist on

Earth, hydrogen is an outstanding chemist in outer space.

Another remarkable property of hydrogen is that its atom emits radiations having a wavelength of 21 centimetres. This is called a universal constant because it is the same throughout the universe. And scientists have taken up the problem of organizing radio communications with other inhabited worlds on the hydrogen wave. If these worlds are inhabited by intelligent creatures, they should have an idea of what 21 centimetres is.

### **How Many Hydrogens Are There on Earth?**

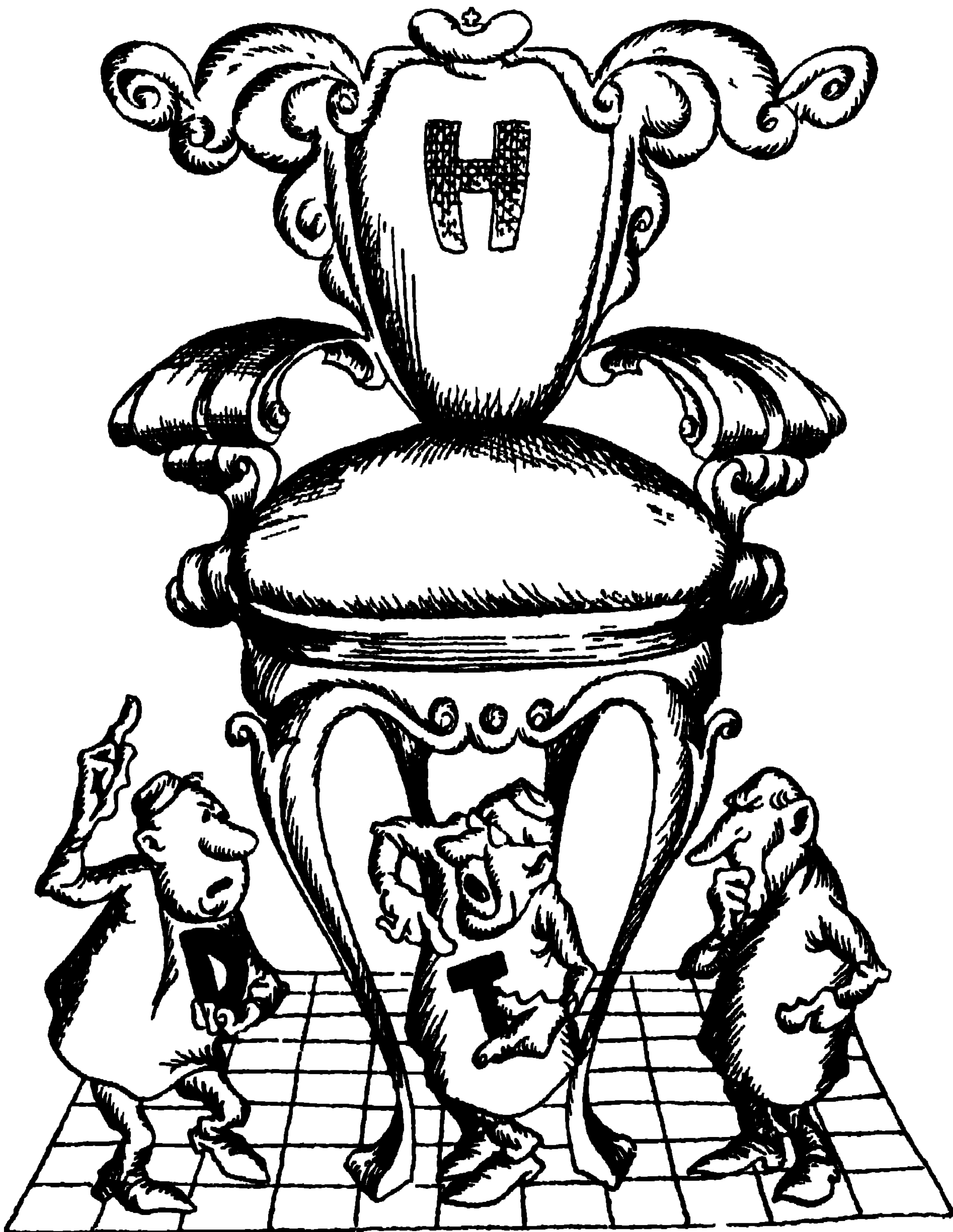
The Nobel Prize is the highest award to a scientist. There are and have been very many scientists in the world, but just over a hundred of them have been awarded the Nobel Prize and they received it for the most outstanding of outstanding discoveries.

Three of the Nobel Prizemen for 1932 were Murphy, Urey and Brickwedde.

It was thought previously that there was only one hydrogen on Earth, that with an atomic weight of one. Murphy and his colleagues discovered a second hydrogen, twice as heavy. This was the hydrogen isotope having the atomic weight two. Isotopes are varieties of atoms with the same charge but different atomic weights. In other words, the nuclei of isotopic atoms contain an equal number of protons but different numbers of neutrons. Isotopes are known for all the chemical elements: some of them exist in nature;

others have been obtained artificially by means of nuclear reactions.

The hydrogen isotope whose nucleus is a bare proton is called protium and its symbol is  $H^1$ . This is the only atomic nucleus which contains no neutrons at all. (Another unique property of hydrogen!)





Add a neutron to this single proton and the result is the nucleus of the heavy hydrogen isotope called deuterium ( $H^2$  or  $D^2$ ). Protium is far more abundant in nature than deuterium, constituting over 99 per cent of all the hydrogen.

But there is a third variety of hydrogen, with two neutrons in its nucleus; this is tritium ( $H^3$  or  $T^3$ ). It forms continuously in the atmosphere under the action of cosmic rays. It forms only to disappear again rather quickly. It is radioactive and decays into a helium isotope (helium-3). Tritium is a very rare element: its content in all the atmosphere of the Earth is only 6 grams. There is only one atom of tritium in every 10 cubic centimetres of air. Just recently still heavier isotopes of hydrogen  $H^4$  and  $H^5$  have been obtained artificially, but they are very unstable.

The mere fact of its having isotopes does not distinguish hydrogen among the chemical elements. What does distinguish it is that hydrogen isotopes differ noticeably in properties, primarily in physical properties. Isotopes of the other elements are almost indiscriminable.

Each variety of hydrogen has its own personality and behaves differently in chemical reactions. For example, protium is more active than deuterium. By studying the behaviour of hydrogen isotopes, scientists started an entirely new branch of science, known as isotope chemistry. The chemistry we know has to do with elements as a whole, with all the isotopes of each, taken together. But isotope chemistry deals with separate isotopes. It enables investigators to look into the most intricate details of various chemical processes.



## **Chemistry = Physics + Mathematics!**

What would you say about a contractor who erected a building and after putting the roof on, asked the designers to calculate whether everything had been done right?

It sounds like an episode from "Through the Looking Glass," doesn't it?

Nevertheless that was just what happened to the Periodic System of Elements. The Big House was first built and the elements lodged, each in a flat of its own. Chemists made Mendeleev's Table their tool. But why the properties of the elements repeat themselves periodically they could not tell for a long time.

The explanation was supplied by the physicists. They calculated the structure of the Periodic System building for strength, and their findings were remarkable. They found it to have been built absolutely right in accordance with all the laws of "chemical mechanics." And so we cannot but admire Mendeleev's truly great intuition and profound knowledge of chemistry.

Physicists began by studying the structure of the atom in detail.

The heart of the atom is its nucleus. Around it revolve electrons, the number of which equals the number of positive charges on the nucleus. Hydrogen has one electron, potassium—twenty, uranium—ninety-two. How do they revolve? Chaotically, like a swarm of moths fluttering around an electric light bulb, or in some definite order?

To answer this question the scientists had to resort to new physical theories and to develop

new mathematical methods. And here is what they found: electrons revolve around the nucleus on definite orbits, like the planets around the Sun.

"How many electrons are there on each orbit? Any number at all or a limited number?" asked the chemists.

"A strictly limited number!" replied the physicists. "All electron shells possess a finite capacity."

Physicists have their own symbols for electron shells. They use letters *K*, *L*, *M*, *N*, *O*, *P*, and *Q*. These letters denote the shells in order of their remoteness from the nucleus.

In collaboration with mathematicians, the physicists drew up a detailed scheme indicating how many electrons each orbit contains.

The *K*-shell can have 2 electrons and no more. The first of them appears in the hydrogen atom, and the second in the helium atom. That is why the first period of the Mendeleyev Table consists of only two elements.

The *L*-shell can accommodate many more, namely, 8 electrons. We find the first electron belonging to this shell in the lithium atom and the last in the neon atom. The elements from lithium to neon form the second period of Mendeleyev's System.

And how many electrons are there in the subsequent shells? The *M*-shell accommodates 18, the *N*-shell 32, the *O*-shell 50, the *P*-shell 72, etc.

If the outermost electron shells of two elements are identically arranged, the properties of the elements are similar. For instance, lithium and sodium, each contains a single electron in its outer shell. And this accounts for their being in the

same group of the Periodic System, namely, in the first group. Note that the group number equals the number of valence electrons in the atoms of the elements in the group.

And now the conclusion: outer electron shells of identical structure recur periodically. And that is why the properties of the elements also recur periodically.

### **Some More Mathematics**

There is logic in everything. Even the most unaccountable phenomenon has its logic. It may not be perceptible at first, and then inconsistencies appear. Inconsistencies are very unpleasant things for any theory or hypothesis. They either disclose the wrongness of the theory or make one think hard. And it often so happens that this hard thinking helps to penetrate deeper into the uncomprehensible.

Here is an example of such an inconsistency. Equality reigns only in the first two periods of the Periodic Table. There are exactly as many elements in each of these periods as the corresponding outer shell can hold electrons. Thus, in the atoms of the elements of the first period, hydrogen and helium, the *K*-shell is filled. It cannot contain more than two electrons, and therefore there are only two elements in the first period. An eight-electron (octet) shell fills up completely through the atoms of the elements of the second period, from lithium to neon, and that is why the second period contains eight elements.

After this things get more involved.

Count up the number of elements in the sub-

sequent periods. There are 8 in the third, 18 in the fourth, 18 in the fifth, 32 in the sixth, and there should also be 32 in the seventh (which is incomplete as yet). But what about the corresponding shells? Here the figures are different: 18, 32, 50, and 72 . .

Now, were we not too hasty in concluding that in undertaking to explain the structure of the Periodic Table the physicists found no defects in its construction? It would be a good thing if a definite electron shell were filled regularly in the inhabitants of each floor of the Big House, and if each floor started with an alkali metal and ended in an inert gas. The capacity of each period would then be equal to the capacity of the electron shell .

Alas, we are obliged to speak of this in the subjunctive mood: if this, if that . . Actually the balance does not tally. The third period of Mendeleev's Table accommodates less inhabitants than there are electrons in the third shell, the *M*-shell. And so on

A sad incongruity. . . But this incongruity holds the clue to the essence of the Periodic System.

Now look: though the third period ends in argon, the third *M*-shell of the latter's atom is not completed. The completed shell should contain 18 electrons, but so far there are only 8 in it. Argon is followed by potassium which belongs to the fourth period, being the first inhabitant of the fourth floor. But instead of placing its latest electron in its third shell, the potassium atom prefers having it in its fourth, *N*-shell. This is no accident, but again a strict regularity established by the physicists. It is simply that no atom can

have more than 8 electrons in its outside shell. The combination of 8 outer electrons is a very stable arrangement.

In calcium, potassium's next-door neighbour, the newest electron also finds it "more advantageous" to occupy the outermost shell, because then the energy supply of the calcium atom is smaller than with any other electron distribution. But in scandium, which follows calcium, the tendency to continue filling the outer shell of the atom vanishes. Its new electron "dives" into the incomplete second-last *M*-shell. And since this shell has ten vacancies (we already know that the maximum capacity of the *M*-shell is 18 electrons), the atoms of the next ten elements, from scandium to zinc, gradually fill up their *M*-shells. Finally, in zinc, all the electrons of the *M*-shell are in place. After this the *N*-shell again begins to accept electrons. As soon as it contains a total of 8 electrons we get the inert gas krypton. In rubidium the old story repeats itself: the fifth shell appears before the fourth is complete.

Such a step-by-step filling of electron shells is a "standard of behaviour" for the inhabitants of the Periodic Table from the fourth period on. This is the basic strict regulation of the Big House of Chemical Elements.

For this reason main and secondary subgroups are distinguished in it. The elements in which the outermost electron shells are being filled comprise the main subgroups. Those in which inner shells are being completed make up the secondary subgroups.

But the fourth, *N*-shell, does not fill up in one step. Its completion is drawn out into three whole

storeys of the Big House The first electron of this shell appears in potassium which occupies flat 19. But the 32nd electron appears in it only in lutetium, a representative of the sixth period Its atomic number is 71

So you see, the incongruity has a silver lining. In trying to account for it we and the physicists got a better insight into the structure of the Periodic System

### **How Chemists Came Across the Unexpected**

You have probably read the splendid science-fiction novel by Herbert Wells called "The War of the Worlds," about the invasion of Earth by emissaries from Mars

You will recall that after the last Martian was killed and life on the Earth began to settle down again, the scientists, having recovered from the shocks they had undergone, hurried to study the little that was left of the unexpected visitors from the neighbouring planet. Among other things, they were interested in the mysterious black dust which the Martians used to destroy life on Earth.

After several unsuccessful experiments which ended in terrible explosions, they found the ill-starred substance to be a compound of the inert gas argon with some elements not yet known on Earth

However, at the time the great writer of science fiction was putting the finishing touches to his book, chemists were absolutely certain that argon could not combine with anything under



any conditions. A large number of practical experiments had brought them to this conclusion.

Argon was called an inert gas. "Inert" comes from the Greek for "inactive." Argon is a member of a whole group of chemical sloths, which also includes helium, neon, krypton, xenon and radon.

In the Periodic System they form what is known as the zero group, because the valence of these elements equals zero. The atoms of the inert gases are capable neither of donating nor of accepting electrons.

What didn't chemists do to make them react! They heated them to temperatures at which the most refractory metals would turn into boiling hot liquids; they cooled them until they became solids; they passed enormous electric discharges through them, and they subjected them to attack by the most furious chemical agents. But all in vain!

Where other elements would long have surrendered and entered into chemical union, the inert gases remained impassive. "You are wasting your time," they seemed to say to the investigator. "We have no desire to enter into any reaction. We're above all that!" And their arrogance earned them another title, that of "noble" gases. But then this title has an ironic tinge to it.

Ramsay, who discovered helium in terrestrial minerals, had reason to be proud; he had presented the world with a new chemical element which really existed. A chemical one! Sir William Ramsay would have paid dearly to make helium behave like the other inhabitants of the Periodic

Table, namely, to combine with hydrogen, oxygen, or sulphur. So that esteemed professors could tell from their rostra, about the oxides and salts of helium.

But helium, the first in the group of inert gases, failed him. At the end of the last century the British scientists Ramsay and Rayleigh discovered neon and argon, krypton and xenon. Later radon closed the list of chemical sloths. They were all elements with atomic weights of their own. But honestly, one could hardly bring oneself to prefix the word "chemical", say, to the words "element argon."

And so scientists moved this arrogant family of noble gases to the edge of the Mendeleev Table, adding a new section to it, which they called the zero group. And they wrote in chemical textbooks that there existed chemical elements which were unable to form compounds under any conditions.

It was quite a blow to the scientists: quite against their will, six elements fell out of the sphere of activity of chemical science.

### **A Solution Which Brought No Consolation**

Even Mendeleev was perplexed at first. He even ventured to suggest the "saving" idea that argon was no new element at all. It was, he said, a sort of compound of nitrogen with three atoms in its molecule:  $N_3$ ; like the ozone molecule  $O_3$  which exists alongside the oxygen molecule  $O_2$ .

But finally the facts convinced Mendeleev of his error and he acknowledged Ramsay to be right. And now all the textbooks in the world



name the English scientist as the discoverer of the group of noble gases, and nobody tries to challenge this fact

...For twenty years N. Morozov, a member of the "Narodnaya Volya" group languished in the dungeons of the Schlüsselburg Fort. Afterwards, under Soviet power, he became a world renowned scientist. The impenetrable walls of his stone prison were unable to break his will or to keep him away from scientific work. His persistent studies materialized in a number of daring and original ideas and hypotheses. In prison Morozov finished a study devoted to the Periodic System. In it he predicted the existence of elements which should be chemically inactive.

By the time Morozov was released the inert gases had already been discovered and had found their place in the table of elements.

It is said that Morozov visited Mendeleev not long before the latter's death, and that the two great compatriots had a long talk about the Periodic Law. Unfortunately, the contents of this talk are unknown.

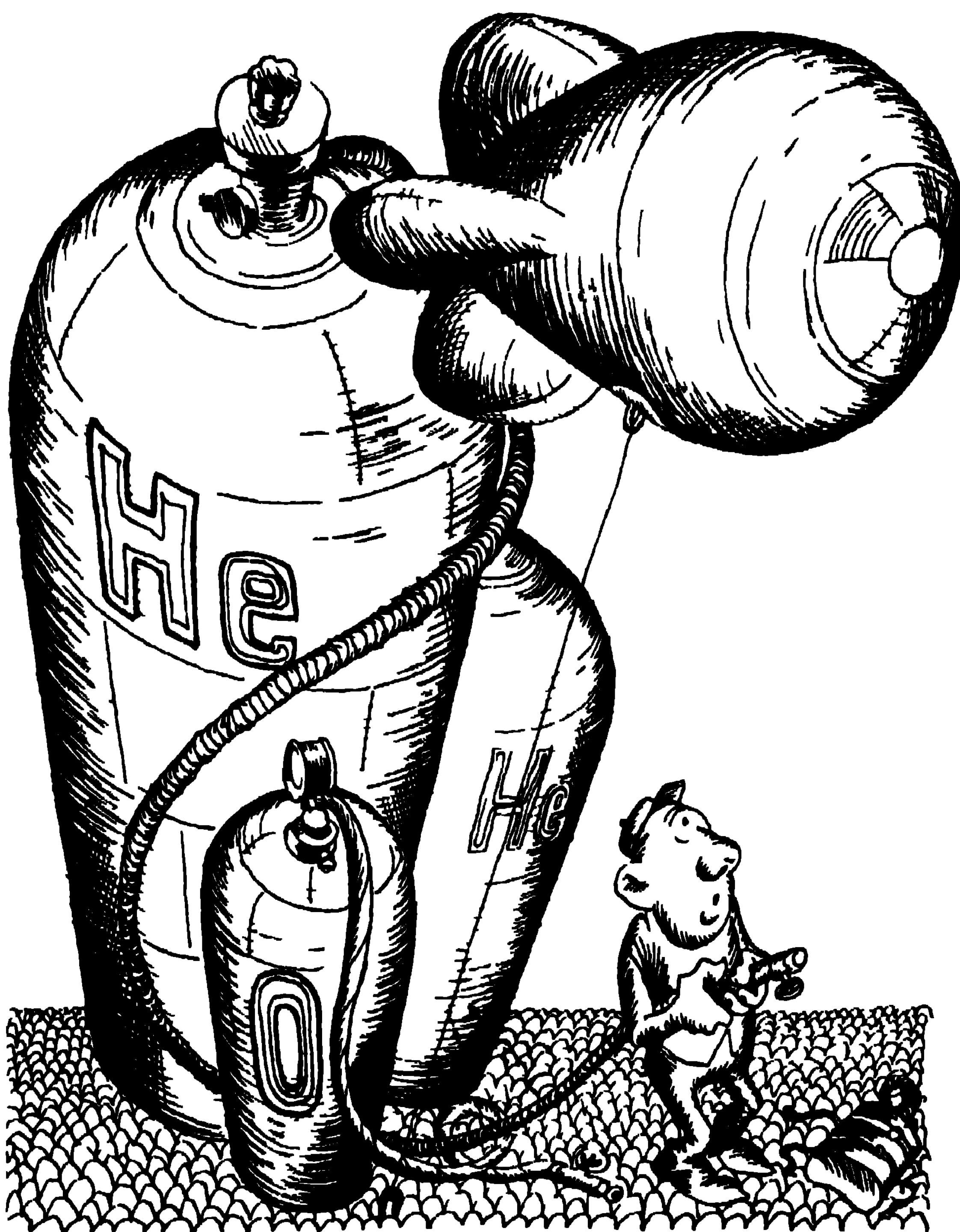
Mendeleev died not long before the mystery of the inertness of the noble gases was solved. The secret was as follows.

The physicists who had so often, and still do, come to the aid of the chemists, established that an outer shell containing 8 electrons is very stable. It is a sort of ideal of stability of an electron shell. And hence, there is no reason for it to donate or accept electrons.

Thus the reason for the "nobility" of the inert gases is the 8 electrons in their outermost shell (or 2—in the case of the helium atom). The two-

electron shell of helium is no less stable than the octet ones of the other chemical sloths

And another thing became clear to the chemists: the addition of the zero group to the Periodic Table was not just a forced measure; without it the Periodic System would have looked like an



unfinished edifice, because each of its periods ends in an inert gas after which the next electron shell begins to fill up and thus the next storey of the Big House begins to form.

As you see, it all turned out quite simple. Despite their aristocratic title, the noble gases exhibited some ability to do practical work: helium found usage for filling balloons and dirigibles and came to the aid of divers against caisson disease. Argon and neon lights decorate city streets at night.

But maybe "nevertheless it does move!" Maybe there is something physicists have not thought out or calculated yet, or perhaps chemists have not yet exhausted all the means of making substances react with one another?

### **The Search for a "Crazy" Idea, or How the Inert Gases Stopped Being Inert**

'Two parallel straight lines never intersect,' asserted geometry through the lips of Euclid, the greatest mathematician of antiquity.

"Not so, they must intersect!" declared the Russian scientist Nikolai Lobachevsky in the middle of the last century.

And thus was born a new geometry, known as non-Euclidean geometry.

"Moonshine and gibberish!" was what many leading scientists said about it at first. But were it not for non-Euclidean geometry we would have neither the theory of relativity nor the daring ideas of the laws governing the structure of the universe.

Many of you have no doubt read A. Tolstoy's "Engineer Garin's Hyperboloid."

"Excellent science fiction," was the verdict of literary critics the world over.

"Fiction that can never become reality!" echoed the scientists.

Tolstoy died only fifteen years before the first ruby crystal emitted a light ray of unheard of brightness and power, and the word "laser" became known to by no means only specialists.

...Enthusiast-chemists continued to believe stubbornly in the possibility of conquering the unheard of obstinacy of the inert gases. If we took the trouble to thumb through the yellowing pages of scientific journals of the twenties, thirties and forties, we should come across quite a few curious articles and notes which show that chemists never relinquished the hope of drawing the inert gases into the sphere of their activities.

Unusual formulas stare out at us from these pages. They tell of strange substances, compounds of helium with mercury, palladium, platinum and other metals. Only one thing is wrong: these are not the chemical compounds we should like to obtain. In them helium's two-electron shell remains unchanged, and the compounds themselves exist only at a very low temperature, in the kingdom of absolute zero. . .

If we went on turning the pages of chemical journals we should come across another bit of news: the Soviet chemist Nikitin prepared a much less fantastic compound of xenon and radon with water, phenol and some other organic liquids:  $\text{Xe} \cdot 6\text{H}_2\text{O}$ , and  $\text{Rn} \cdot 6\text{H}_2\text{O}$ . They are



stable under ordinary conditions, can be readily obtained, but

But as before, chemical bonding has nothing to do with these compounds. The xenon and radon atoms abide piously by the perfection of their outermost shell 8 electrons there were and 8 electrons remained. More than fifty years had passed since the inert gases were discovered, but "the cat had not budged."

The twentieth century, the stormiest and most unforgettable of all the centuries of human history, will come to a close. And scientists will sum up the achievements of scientific thought during the past hundred years. The endless list of outstanding discoveries will include in a pro-

minent place "the production of chemical compounds of the inert gases" And some enthusiastic commentator will add: one of the most sensational discoveries. Sensational? Hardly! Rather a romantic story. Or even a story of how simple sometimes can be the solution of a problem which for dozens of years tormented the minds of numerous scientists with its insolvability...

In our days chemistry resembles a mighty tree with an immense ever-spreading crown. It is no longer possible for any one person to study even a whole branch in full. An investigator mostly has to spend years to become acquainted in detail with a small twig, a bud, or a hardly visible shoot. Knowledge of the branch as a whole adds up from thousands of such investigations.

The "twig" studied by the Canadian chemist Neil Bartlett was a compound called platinum hexafluoride in the language of chemists, and having the formula:  $\text{PtF}_6$ . It was not by accident that he devoted so much time and effort to this substance. Compounds of fluorine with the heavy metals are very interesting substances, of great importance to science and practice. One of their uses is in the separation of the uranium isotopes uranium-235 and uranium-238 for nuclear engineering. The separation of one isotope from another is a very complicated process, but it can be accomplished with the aid of uranium hexafluoride  $\text{UF}_6$ . Besides, heavy metal fluorides are very active chemical substances.

Bartlett reacted  $\text{PtF}_6$  with oxygen and obtained a very curious compound. The oxygen is contained in it as the positively charged molecule  $\text{O}_2^+$ . A molecule which has lost one electron. Now



what is so strange about that? The strange thing is that it is very difficult indeed to tear an electron away from the oxygen molecule, as this requires a great deal of energy. Platinum hexafluoride was found to be capable of removing an electron from the oxygen molecule

Removal of an electron from the outer shells of inert gas atoms also requires a great deal of energy. There is a regularity here according to which the heavier the inert gas the smaller the amount of energy required. And it was found easier to make a xenon atom part with one of its electrons than to tear one away from the oxygen molecule.

And so... This is where the most interesting begins! Bartlett decided to make platinum hexafluoride steal an electron from the xenon atom. And he was successful—the world's first chemical compound of an inert gas was born in 1962. This is what it looks like:  $\text{XePtF}_6$ . And it is fairly stable. Nothing like the exotic compounds of helium with platinum or mercury

This hardly noticeable grain immediately sprouted out. The sprout, which began to grow like bamboo, became a new trend in chemistry, the chemistry of the inert gases. Only yesterday many serious scientists were very sceptical. Today they have at their disposal more than thirty real chemical compounds of the inert gases, mainly fluorides of xenon, krypton, and radon.

And so the myth of the infallibility of the outer electron shell of the noble gases collapsed

What about the molecular structure of the various compounds of the inert gases? Scientists are only just beginning to understand this. It turns

out that atoms can possess a much larger supply of valence forces than was thought previously.

Formerly the valence concept was based on recognition of the special stability, infallibility of the octet shell. But now scientists came up against the question of whether everything was quite so clear in these theories? Maybe it will fall to your lot, dear readers, to help disclose new laws in them.

### **Another Inconsistency! What Is to Be Done About It?**

It is said that once a pensive man walked into a research institute with a well stocked folder under his arm. He spread out his papers before the scientists and declared in a tone that suffered no objection:

“The Mendeleyev Table should have only seven groups of elements, neither more nor less!”

“How is that?” asked the worldly wise scientists in surprise.

“It’s very simple. The number ‘seven’ conceals a profound meaning! There are seven colours in the rainbow, seven notes in the musical scale...”

It was clear to the scientists that the man before them was not quite sane. And they attempted to turn the claims of the latter-day remaker of Mendeleyev’s Table to joke.

“Don’t forget that there are also seven holes in a man’s head!” said one of them with a smile.

‘And seven pillars of wisdom too,’ added another.

This is no anecdote. It actually occurred in one of the Moscow institutes.





There have been multitudes of such cases in the history of the Periodic System Attempt after attempt was made to receive it Sometimes the attempt had some definite sense But most often they were just the result of some authors trying to be original

Mendeleyev's great discovery celebrated its hundredth anniversary in 1969 And to think that in the wake of this great date even serious chemists are coming to the conclusion that something will have to be changed in the Periodic System!

There was a time when scientists could not bring themselves to call the elements of the zero group chemical Now it is the other way around It seems rather inconvenient to call the elements of the zero group inert Hardly a month passes

but several articles appear in chemical journals on the chemistry of the increasingly, the elements of the zero group. Information keeps streaming in from various countries on the synthesis of new chemical compounds of krypton, xenon and radon. . . Bi-, tetra-, and hexavalent xenon, tetravalent krypton—these terms, which seemed crazy only a decade ago, have now become quite common

“A nightmare of xenon fluorides hangs over the Mendeleev Table!” exclaimed an eminent scientist in horror.

Though he may have been exaggerating a bit, this “nightmare” must be dispersed as soon as possible. But how?

Here is what the scientists suggest: send the “zero group” concept to the archives of the history of science and place all the once inert gases in the eighth group, considering that they have eight electrons in their outer shells. . .

But wait! There is already an eighth group, “built into” the table by Mendeleev himself. This group contains nine elements: iron, cobalt, nickel, ruthenium, rhodium, palladium, osmium, iridium, and platinum.

What is to be done about it?

In other words, chemists have come up against another inconsistency. The familiar appearance of the Periodic Table must be changed, and that very soon.

“There is always something in the way” runs the proverb. What is in the way of this change in appearance is the “old” eighth group. Where is it to be placed?

## The "Omnivorous"

That is what the prominent Soviet scientist A. E. Feisman called it. For the world knows no element more ferocious, nature has produced no substance chemically more active than the main character of this story. You will never find it in nature in the native state, but only in the form of compounds.

Its English name is fluorine from the Latin *fluo* meaning "flow". But its Russian name *ftor* is derived from the Greek for "destructive". This is a second, no less forceful term characterizing the main feature of this representative of the seventh group of the Mendeleev Table.

It has been said that "the path to free fluorine led through human tragedy. . ." These are not just fine words. Man has discovered 104 elements. In the hunt for new simple substances researchers overcame a multitude of difficulties, knew many disappointments, became the victims of curious errors. The pursuit of traces of unknown elements has cost scientists a great deal of effort.

Fluorine, the element fluorine in its free form, has cost lives.

Long is the doleful list of casualties incurred in attempts to obtain free fluorine. Knox, a member of the Irish Academy of Science, the French chemist Niklesse, the Belgian researcher Layette, all fell victim to the "omnivorous." And many more scientists suffered severe injuries. Among them were the prominent French chemists Gay-Lussac and Thénard and the English chemist Humphry Davy. . . There were no doubt also unknown investigators on whom fluorine took

revenge for insolent attempts to isolate it from its compounds.

When on June 26, 1886, Henri Moissan reported to the Paris Academy of Science that he had finally succeeded in obtaining free fluorine, he had a black bandage over one of his eyes. . .

The French scientist Moissan was the first to find out what the element fluorine was like in the free state. And it must be owned that many chemists were afraid to work with this element.

Twentieth-century scientists have found methods of bridling the fury of fluorine, have hunted out ways of making it serve mankind. The chemistry of this element has now become a large independent field of inorganic chemistry.

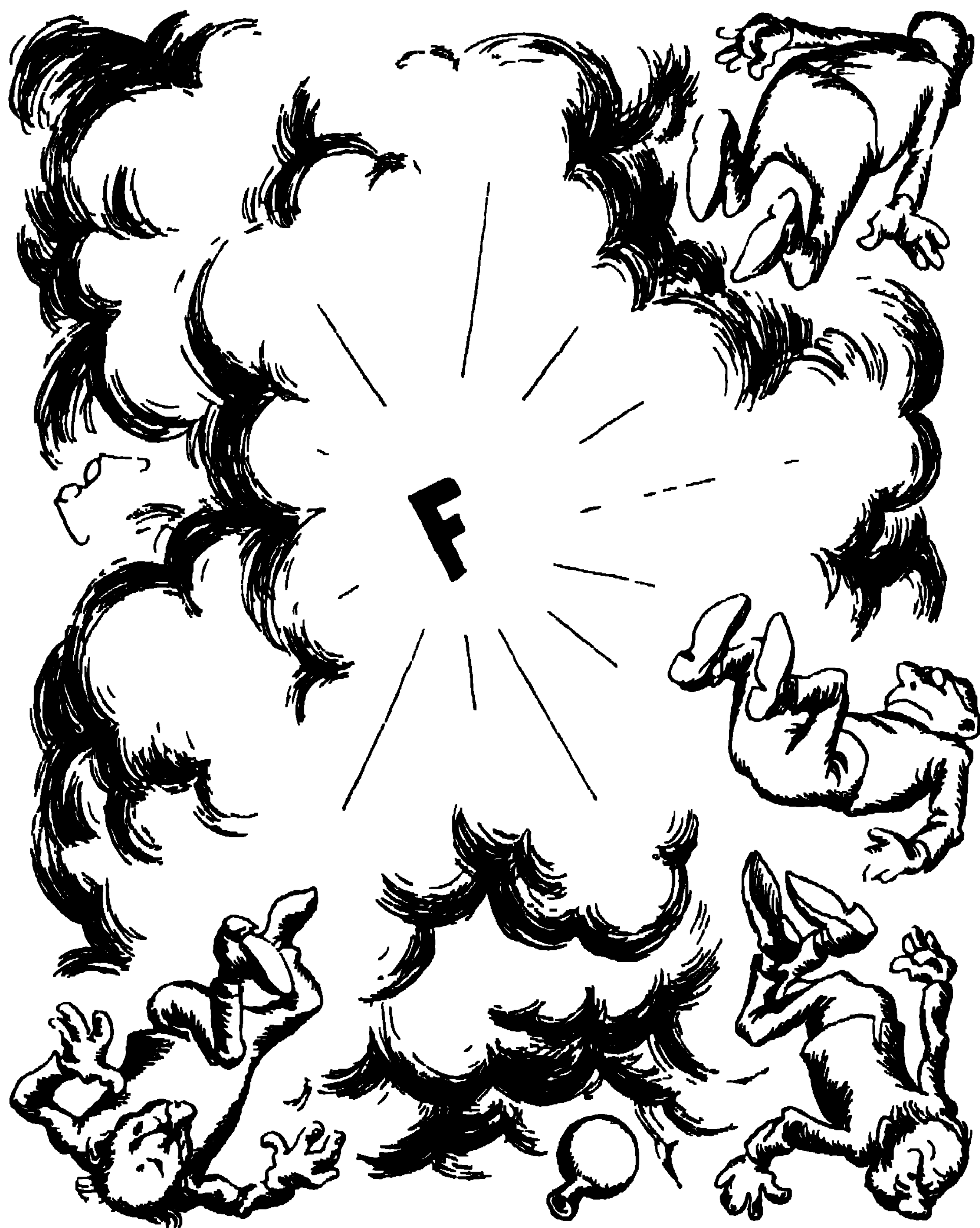
The terrible "genius" of the bottle has been subdued. And the efforts of the numerous fighters for free fluorine have been well repaid.

Many types of modern refrigerators use freon as their cooling agent. Chemists have a more complex name for this substance: difluorodichloromethane. Fluorine is an indispensable constituent of this compound.

Itself "destructive," fluorine can form compounds which practically nothing can destroy. They will not burn nor rot and are insoluble in alkalis and acids; free fluorine does not attack them, and they are almost wholly indifferent to arctic cold and to sudden sharp temperature changes. Some of them are liquids, others solids. Their common name is fluorocarbons, compounds which nature herself was unable to invent. They were produced by man. The union of carbon and fluorine was found very useful. Fluorocarbons are employed as cooling fluids in motors, for impreg-

nating special fabrics, as very long-lived lubricants, insulators and structural materials for various kinds of equipment in the chemical industry.

When the scientists were searching for ways of harnessing nuclear energy, it became neces-



sary to separate the uranium isotopes uranium-235 and uranium-238. And as has already been said above, investigators succeeded in accomplishing this very complicated task with the aid of a very interesting compound called uranium hexafluoride.

It was fluorine which helped chemists to prove that the inert gases were not at all chemical sloths as had been thought for decades. The first compound of the inert gas xenon brought to life was its compound with fluorine

Such is fluorine's work record.

### **Henning Brand's "Philosopher's Stone"**

There once lived in the Middle Ages in the German town of Hamburg a merchant by the name of Hennig Brand. We do not know how inventive he was in his trade operations, but can assert confidently that he had only a very crude idea of chemistry.

But even he could not resist the temptation to try and become a rich man all at once. This seemed easy: all he had to do was to find the notorious "philosopher's stone" which, the alchemists claimed, could change even a cobblestone to gold.

...Years passed. Brand's name was mentioned less and less frequently in conversations between merchants, and when it was, heads were wagged sadly. Meanwhile he dissolved, mixed, sieved, and calcined various minerals and concoctions, and his hands were covered with unhealing acid and alkali burns.

One fine evening the former merchant had a



streak of luck. A substance, white as snow, settled at the bottom of his retort. It burned quickly, forming thick asphyxiating fumes. And the strangest thing was that it glowed in the dark. The cold light it gave off was so bright that Brand could read his ancient alchemical treatises by it (for him these treatises had now taken the place of business letters and receipts).

...Thus was discovered by mere chance the chemical element phosphorus. Its name is from the Greek for "light-bearing" or "light-bearer."

Phosphorus is the main component of many luminous compounds. Do you remember the famous Dog of the Baskervilles that Sherlock Holmes hunted for so long? Its mouth was smeared with phosphorus.

No other representative of the Periodic Table possesses such a unique property.

The valuable and important properties of phosphorus are legion.

The German chemist Moleschott once said: "Without phosphorus there is no thought." This is true, because cerebral tissues contain many complex phosphorus compounds.

But neither is there life without phosphorus. Without it respiratory processes would be impossible and muscles could store no energy. Finally, phosphorus is one of the most important "bricks" of any living organism. As a matter of fact, the principal component of bony tissue is calcium phosphate.

Now is this not just as good as the "philosopher's stone", seeing that it animates the inanimate?

And lastly, why does phosphorus glow?

There is always a cloud of phosphorus vapours over white phosphorus. These vapours become oxidized, evolving a large amount of energy. The latter excites the phosphorus atoms and this causes the glow.

### **The Odour of Freshness, or the Transition of Quantity into Quality Exemplified**

Your breath comes easier after a thunderstorm. The air is clear and charged with freshness.

This is not just a poetical image. Thunderclaps result in the formation of ozone gas in the atmosphere, and it is this gas that makes the air seem cleaner.

Ozone is essentially oxygen. The difference is that the oxygen molecule contains two atoms of





the element, while the ozone molecule contains three.  $O_2$  and  $O_3$ —one atom more or one atom less of oxygen, should that make a big difference?

It does make a very big difference: ozone and oxygen are entirely different substances.

Without oxygen there is no life. On the other hand, ozone in large concentrations kills all living things. It is a most powerful oxidizing agent, second only to fluorine. On combining with organic substances ozone immediately destroys them. When attacked by ozone all the metals, except for gold and platinum, change rapidly into their oxides.

It is two-faced! A murderer of all living things, ozone also promotes life on the Earth in many ways.

This paradox is easy to explain. Solar radiations are not uniform. They contain what are known as ultraviolet rays. If all these reached the Earth's surface, life on Earth would be impossible because these rays carry an immense amount of energy and are fatal to living organisms.

Fortunately, only a very small fraction of the Sun's ultraviolet rays reach the Earth's surface. Most of them lose their force in the atmosphere at an altitude of 20-30 kilometres. At this level of the air blanket enveloping our planet, there is a great deal of ozone. And it absorbs the ultraviolet rays.

By the way, one of the present-day theories of the origin of life on Earth relates the appearance of the first organisms to the time of formation of the ozone layer in the atmosphere.

But people need ozone on the Earth too, and

in large quantities.

They, and primarily chemists, need thousands and thousands of tons of ozone very badly.

The chemical industry would gladly make use of the astounding oxidizing power of ozone.

Oil industry workers would also be pleased to bow down to ozone. The petroleum of many oil fields contains sulphur. Sour oils, as they are called, cause a great deal of trouble, for one thing, by rapidly corroding equipment, for instance, boiler stokers at power stations. With ozone such oils could easily be freed from sulphur, and the sulphur removed could be utilized to double or even treble the present production of sulphuric acid.

We drink chlorinated water. It is harmless, but its taste is inferior to that of spring water. Drinking water treated with ozone is absolutely free from pathogenic bacteria and has no unpleasant taste.

Ozone can renew old automobile tyres and bleach fabrics, cellulose, and yarn. There are many other things it can do. And that is why scientists and engineers are working on the design of high-capacity industrial ozonizers.

That is what ozone is!  $O_3$  is no less important than  $O_2$ . Philosophy has long ago formulated the dialectical principle of the transition of quantity into quality. The example of oxygen and ozone is one of the most vivid manifestations of dialectics in chemistry.

There is another molecule known to scientists, consisting of four oxygen atoms,  $O_4$ . However, this "quartet" is very unstable and hardly anything is known so far about its properties.

## So Simple And Yet So Wonderful

Before the war there was a merry comedy on at the movies, called "Volga, Volga." In it a blithe water carrier sings as he whips up his lazy horses:

"For water's needed everywhere  
Without't you're neither here nor there "

The song was a great success and has now even become proverbial.

But this simple ditty holds profound implications.

For water really is substance No. 1 in life.  $H_2O$ . One atom of oxygen plus two atoms of hydrogen. Probably one of the first chemical formulas you ever learn. Now try to imagine what would become of our planet if the water suddenly disappeared from it.

...Dismal yawning "cavities" of sea and ocean hollows covered with a thick layer of the salt once dissolved in the water. Dry river channels, springs which will never bubble again. Rocks disintegrated to ash: water was one of their main constituents.

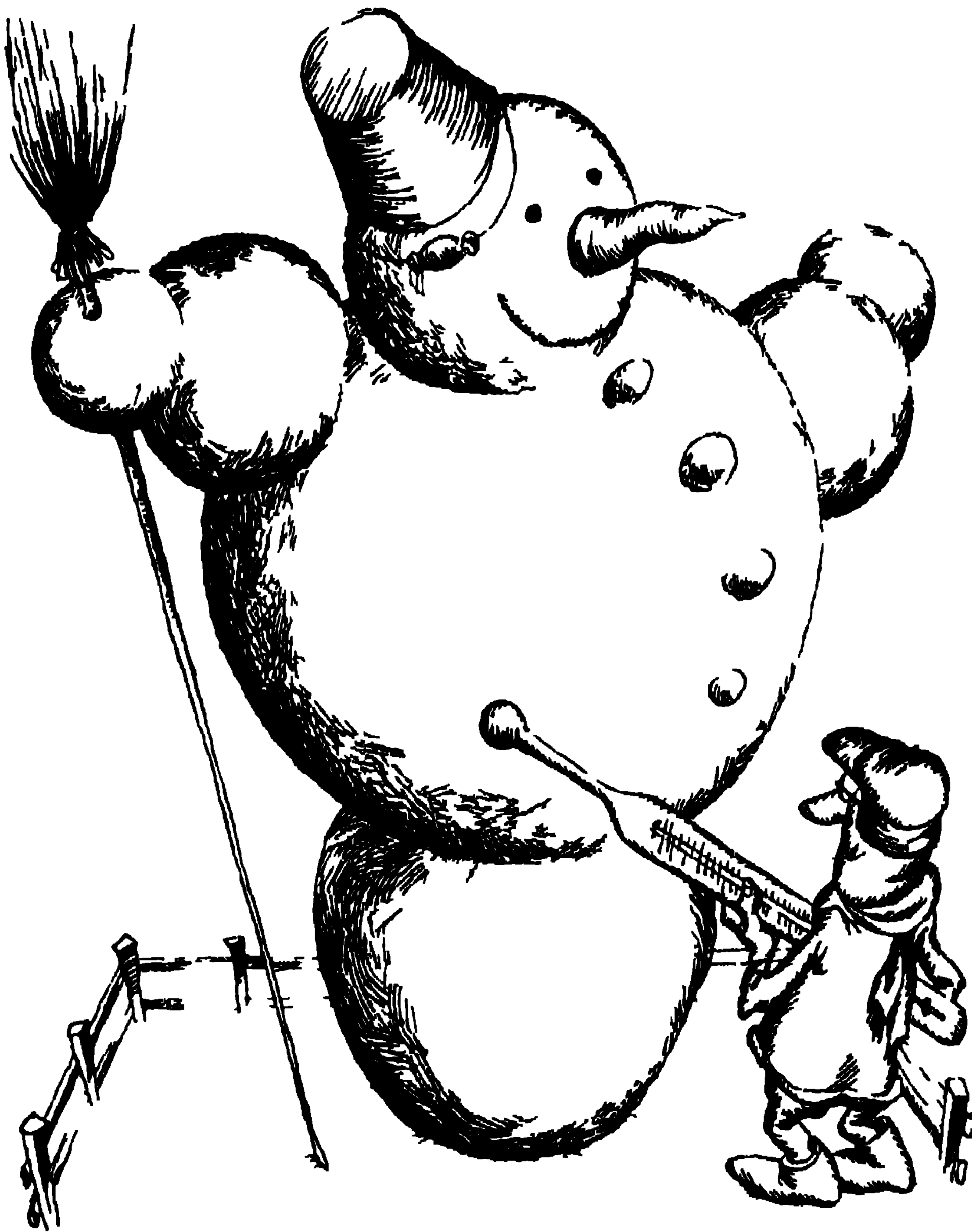
Neither bush nor flower, not a living thing on the dead Earth. And above it a cloudless sky of a horrifying unusual colour.

So simple a compound, and yet where there is no water, no life, intelligent or unintelligent, is possible.

Why? First of all because water is the most remarkable chemical compound in the world.

When Celsius invented his thermometer, he

based his device on two values, or two constants: the boiling point and the freezing point of water. He took the former as equal to  $100^{\circ}$ , and the second to zero. Then he divided the interval between them into 100 divisions. Thus appeared the first instrument for measuring temperatures.



But what would Celsius have thought if he knew that actually water should not freeze at all at zero nor boil at 100 degrees?

Nowadays scientists have established that in this respect water is a great fraud. It is the most anomalous compound on the globe.

Here is what scientists claim: water should boil at a temperature 180° lower, i. e. at minus 80 degrees. At any rate, the regulations current in the Periodic System would have it boil at such an antarctic temperature.

The properties of the elements of any one group of the Periodic System gradate quite regularly from the light elements to the heavy ones. Take, for instance, the boiling point. The properties of compounds do not vary just any old way, but depend on the location of the elements, comprising the molecule, in the Mendeleev Table. This refers, in particular, to hydrogen compounds, to hydrides of elements of the same group.

Hydrogen may be called oxygen hydride. Oxygen is a member of the sixth group, which also includes sulphur, selenium, tellurium, and polonium. The hydrides of all these elements have the same molecular pattern as the water molecule:  $\text{H}_2\text{S}$ ,  $\text{H}_2\text{Se}$ ,  $\text{H}_2\text{Te}$ , and  $\text{H}_2\text{Po}$ . The boiling points of these compounds are known to gradate regularly from sulphur to its heavier brothers. And unexpectedly we find that the boiling point of water falls out of this series, being much higher than it should be. Water refuses to acknowledge the rules of behaviour established for the Periodic Table, as it were, and postpones its transition to the vapour state for 180 degrees. This is

only the first amazing anomaly of water.

Its second anomaly has to do with its freezing point. The laws of the Periodic System specify that water shall solidify at a temperature of 100 degrees below zero. Water violates this requirement harshly and turns to ice at zero.

This wilfulness of water suggests that its liquid and solid states are abnormal on Earth.

According to the rules water should exist here only in the vapour form. Now imagine a world where the properties of water obey the strict regularities of the Periodic System. For fiction writers such a unique picture would be an excellent basis for thinking up amusing novels and stories. But for us, and for scientists, it is further evidence that the Periodic Table is a much more complex structure than it seems at first glance and that the characters of its inhabitants very greatly resemble those of live people in that they cannot be confined to definite bounds. Water is of a wilful character. . .

But why?

Because the molecules of water have a specific arrangement and for this reason possess a pronounced ability to attract one another. In vain would we look for single molecules in a glass of water. The molecules form groups which scientists call associations. And it would be more correct to write the formula of water as  $(\text{H}_2\text{O})^n$ , the subscript  $n$  indicating the number of molecules in the association. These associative bonds between the water molecules are very difficult to break. And that is why water freezes and boils at much higher temperatures than would be expected.

## **"Ice, Not Yet Firm, on the Cold Little River..."**

In 1913 news of a grave tragedy spread all over the world. The huge ocean liner "Titanic" ran into an iceberg and sank. Experts gave various reasons for the catastrophe. It was said that owing to a fog the captain could not see the immense floating mountain of ice in time, and the ship collided with it and so perished.

If we consider this tragic event from the standpoint of a chemist, we come to a quite unexpected conclusion: the "Titanic" fell victim to another anomaly of water.

Frightful mountains of ice—icebergs—float like cork on the surface of water, though these mountains weigh tens of thousands of tons.

This is possible only because ice is lighter than water.

Try melting any metal and throwing a piece of the solid metal into the liquid: it will sink immediately. The density of any substance in the solid state is higher than in the liquid. Ice and water are an astonishing exception to this rule. But were it not for this exception, all the bodies of water in the middle latitudes would soon freeze in winter right down to the bottom and all living things in them would perish.

Remember Nekrasov's poem:

"Ice, not yet firm, on the cold little river  
Like melting sugar, in patches is spread." \*

When the frosts come the ice hardens. A winter road can be laid on the river. But under the

---

\* Translation by Juliet M. Soskice.



thick layer of ice water continues to flow as before. The river never freezes to the bottom.

Ice, the solid state of water, is a very peculiar substance. There are several kinds of ice. The one found in nature is that which melts at zero (of the Celsius scale). By using high pressures scientists have obtained six more varieties of ice in the laboratory. The most fantastic of them (ice VII), occurring at pressures over 21,700 atmospheres, might be called red-hot ice. It melts at 192°C above zero when the pressure is 32,000 atmospheres.

It would seem that there could hardly be anything more familiar than the picture of ice melting. But what surprising things it involves!

After melting any solid begins to expand. But the water that forms when ice melts behaves quite differently: it contracts and only afterwards, if the temperature continues to rise, does it begin to expand. This is again due to the ability of water molecules to attract one another. At four degrees above zero this ability becomes especially pronounced, and therefore at this temperature the density of water is at its highest; that is why our rivers, ponds and lakes do not freeze to the bottom even in the coldest weather. The coming of spring makes everyone glad; we have all taken pleasure in the golden days of autumn. The joyous spring thaw and the crimson attire of the woods...

Again the result of an anomalous property of water!

A great deal of heat is required to melt ice, much more than to melt the same quantity of any other substance.



When water freezes this heat is evolved, and in returning it, ice and snow warm the Earth and the air. They soften the sharp transition to severe winter and enable autumn to reign for several weeks. In the spring, on the contrary, the melting of the ice holds back the sultry weather for a time.

### **How Many Waters Are There on Earth?**

Three isotopes of hydrogen have been found by scientists in nature, and each of them can combine with oxygen. Hence, one may speak of three kinds of water: protium, deuterium, and tritium waters:  $\text{H}_2\text{O}$ ,  $\text{D}_2\text{O}$  and  $\text{T}_2\text{O}$ , respectively.

There may also be "mixed" waters containing, say, an atom of protium and an atom of deuterium, or an atom of deuterium and one of tritium in their molecules. This increases the list of waters:  $\text{HDO}$ ,  $\text{HTO}$ , and  $\text{DTO}$ .

But the oxygen contained in the water is also a mixture of three isotopes: oxygen-16, oxygen-17 and oxygen-18, the first being by far the most common.

Taking into account these varieties of oxygen, another 12 possible waters can be added to the list. When you draw a cup of water from a lake or river, you probably never suspect that you have in your cup eighteen different kinds of water.

And so water, no matter where it comes from, is a mixture of different molecules, the lightest being  $\text{H}_2\text{O}^{16}$  and heaviest,  $\text{T}_2\text{O}^{18}$ . Chemists can now prepare each of these eighteen kinds of water in the pure form.

Hydrogen isotopes differ perceptibly in their properties. And what about the different kinds of water? They differ in some ways, too. For example, they have different densities, and different freezing and boiling points.

And still the relative content of the different kinds of water in nature is always and everywhere different.

For example, tap water contains 150 grams of heavy deuterium water,  $D_2O$ , per ton. But its content in the water of the Pacific Ocean is noticeably higher: about 165 grams. A ton of ice from the Caucasian glaciers contains 7 grams of heavy water more than a cubic metre of river water. In a word, the isotopic composition of water is different everywhere. The reason for this is that there is a mighty process of isotope exchange occurring continuously in nature. The different hydrogen and oxygen isotopes keep replacing one another under various conditions.

Is there any other natural compound with as large a number of varieties? There is not.

Of course, we have to do mainly with protium water. But the other kinds of water cannot be disregarded. Some of them are widely used in practice, especially heavy water  $D_2O$ . It is used in nuclear reactors for moderating neutrons which cause uranium fission. Besides, scientists use various kinds of water for investigations in the field of isotope chemistry.

Eighteen kinds, and no more? Actually, the varieties of water may be much more numerous. Besides the natural isotopes, there are also man-made radioactive isotopes of oxygen: oxygen-14, oxygen-15, oxygen-19, and oxygen-20. And just

Recently the number of hydrogen isotopes has also increased: we can now speak of  $H^4$  and  $H^5$ .

Now if we take into account the man-made isotopes of hydrogen and oxygen, the list of possible waters increases to over 100. You can easily count up the exact number yourself. . .

### **“Water of Life”, Life-Giving, Omnipresent Water**

Multitudes of folk tales of various peoples are based on the legend of the “water of life.” It healed wounds and revived the dead. It made the coward brave and increased the strength of the brave a hundredfold.

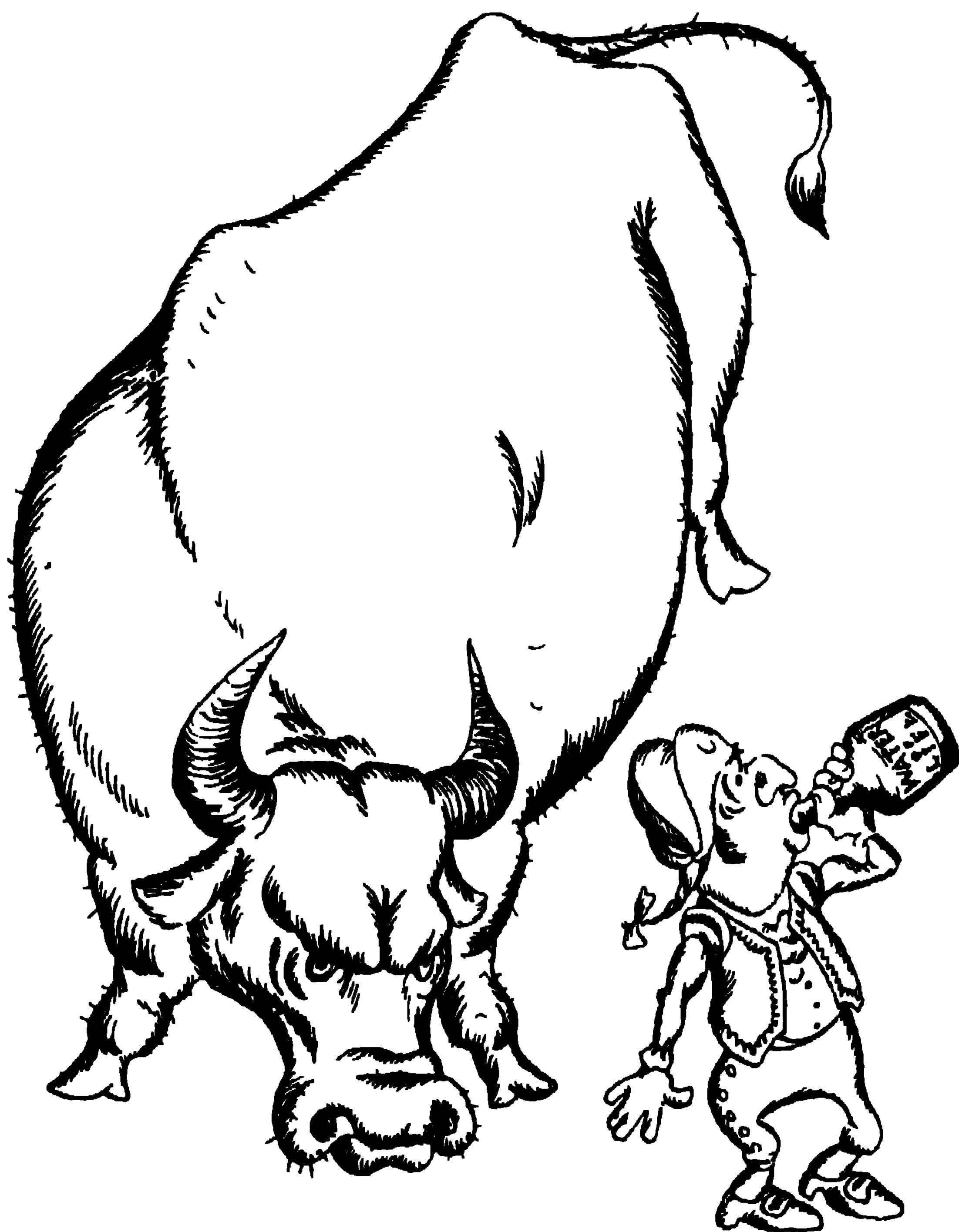
It is not by chance that man attributed such magic properties to water. The very fact that we are alive on Earth, that we are surrounded by green woods and flowering fields, that we can go boat riding or run through puddles under the rain in summer and go skiing or skating in winter—is all due to water. To be more exact, all this is due to the ability of water molecules to attract each other and form associations. This is one of the conditions for the origin and development of life on our planet.

The history of the Earth is primarily the history of water. It has continuously changed and still goes on changing the face of our planet.

Water is the greatest chemist in the world. No natural process takes place without it—be it the formation of a new rock, a new mineral, or a highly complicated biochemical reaction taking place in the organism of a plant or an animal.

Chemists could hardly do anything in their laboratories without water. In studying the pro-

perties of substances, their transformations, in producing new compounds they can get along without water only in rare cases. Water is one of the best solvents known And many substances must be dissolved before they can enter into reactions.



What happens to a substance when it dissolves? The forces acting between the molecules and atoms at its surface are weakened many hundredfold in water, as a result of which they break away from the surface and pass into the water. In a glass of tea a piece of sugar breaks down into separate molecules. Table salt decomposes into charged particles known as sodium and chloride ions. Owing to its peculiar structure the water molecule possesses a great ability to attract the atoms and molecules of a dissolving body. Many other solvents are inferior to water in this respect.

There is not a rock on the Earth that can resist the destructive action of water. Even granites yield slowly but surely. Water carries the substances it dissolves off to the seas and oceans. That is what makes these tremendous bodies of water salty, though hundreds of millions of years ago the water in them was fresh...

### **The Icicle's Secrets**

Little children adore playing with icicles. They are such pretty, glistening things. But before you know it the child has got the icicle in its mouth. Is it so tasty? Try to take it from him and you'll see.

An amusing childish whim? No, it is far more serious than that.

The following experiment was performed on little chicks. One group was given ordinary water to drink, while the other was allowed to drink only snow melt water with pieces of ice floating in it.

The test could hardly have been simpler. But the results were surprising. The chicks drinking the ordinary water would do so serenely and without fuss. But the basin of melt water was always a virtual battlefield. The chicks swallowed the water as greedily as if it were something unusually tasty.

A month and a half later the experimental birds were weighed. Those brought up on melt water were much heavier, had gained more weight than the chicks which had been drinking ordinary water.

In a word, snow melt water possesses certain wonderful properties. It is very beneficial to live organisms. Why is this so?

At first it was thought to be due to the higher deuterium content in the melt water. In small concentrations heavy water stimulates the development of living organisms. But this was only partly true. . .

Now it is believed that the true reason lies elsewhere, in the very process of melting.

Ice has a crystalline structure. But, generally speaking, water is also a liquid crystal. Its molecules are not in complete disorder, but form a strict openwork skeleton. Of course, the structure of the latter differs from that of ice.

When ice melts its structure persists for a fairly long time. Outwardly melt water is a liquid, but the molecules in it remain in "ice formation". For this reason the chemical activity of melt water appears higher than that of ordinary water. It participates readily in a multitude of biochemical processes. When taken up by an organism it com-



bines with various substances more easily than ordinary water.

Scientists believe that the structure of water in an organism greatly resembles the structure of ice. When ordinary water is assimilated by an organism, its structure has to be rearranged. Melt water already has the right structure and so the organism does not have to spend any extra energy on rearranging its molecules.

Evidently, the role of melt water in life is very great.

### **A Bit of Linguistics, or Two Very Different Things**

Without words there can be no speech, without letters, no words. We begin to study a language by learning the alphabet. Each alphabet contains two kinds of letters, vowels and consonants. Without either of these human speech would just go to pieces. . . . There is a scientific fiction novel in which the inhabitants of an unknown planet speak to each other by means of sounds consisting only of consonants. But that is pure science fiction!

Nature speaks to us in the language of chemical compounds. And each of these is a sort of combination of chemical "letters," or elements occurring on Earth. The number of such "words" exceeds three million. But there are only just over a hundred "letters" in the chemical "alphabet."

This "alphabet" also contains "vowels" and "consonants." The chemical elements have for ages been divided into two groups: nonmetals and metals.

Nonmetals are much less numerous than metals. The ratio between them resembles a basketball score—21 : 83. . . Quite like in human speech, which has much fewer vowel than consonant sounds.

A combination of only vowel sounds in human speech rarely expresses anything articulate. It is most often something like a senseless howl.

In the chemical language combinations of only “vowels” (nonmetals) are rather common. All life on Earth owes its existence to compounds of the nonmetals with each other.

Not in vain do scientists call the four main nonmetals—carbon, nitrogen, oxygen, and hydrogen—organogens, meaning substances which give rise to organic life. If we add phosphorus and sulphur, these six “bricks” just about exhaust the list of materials used by nature to build proteins and hydrocarbons, fats and vitamins—in a word, all vital chemical compounds.

Two nonmetals, namely, oxygen and silicon (two “vowels” of the chemical “alphabet”) combine to form a substance written  $\text{SiO}_2$  and read silicon dioxide in the language of chemistry. This substance is the ultimate foundation of the Earth’s firmament, a kind of cement which keeps all the rocks and minerals from falling apart.

It doesn’t take much more to complete the list of “vowels” of the chemical “alphabet”. All we have to add are the halogens, the rare gases of the zero group (helium, and its brothers) and three not very well known elements, boron, selenium and tellurium.

However, it would be wrong to say that all



living things on Earth are made up only of non-metals.

Scientists have detected more than seventy different chemical elements in the human organism: all the nonmetals and a great number of metals, from iron to the radioactive elements, including uranium.



The reason why there are more consonants than vowels in the human language has long been a point of controversy among linguists.

Chemists are interested in why there are two such different groups as nonmetals and metals in the Periodic System. Each of these groups includes elements which differ greatly from one another, but there is nevertheless some resemblance between them.

### **Why "Two Very Different Things"?**

A jester once remarked that two basic qualities distinguish humans from animals: their sense of humour and their sense of historical experience. A human being is capable of laughing over his own misfortune, and will not be caught a second time where he has stumbled once. We might add another quality, that of asking "why" and trying to find the answer.

And now let us use this little word "why."

For instance, why are the nonmetals not distributed evenly over the storeys and sections of the Big House, but grouped in definite part of it. Metals are metals and nonmetals are nonmetals, but what is the difference between them? Now that is a good question to start with.

When two elements (no matter which) react, the outermost electron shells of their atoms are rearranged. The atoms of one of the elements gives away electrons, and those of the other accepts them.

Now the difference between metals and nonmetals lies in this most important chemical law.

Nonmetals are capable of two opposite actions:

as a rule, they acquire electrons, but they are also capable of giving them away. Their behaviour is pliable and they can change their aspect depending on the circumstances. If they find it more profitable to accept electrons, nonmetals appear as negative ions. If not, they form positive ions. Only fluorine and oxygen know no compromise: they only accept electrons and never give them away.

Metals are much less "diplomatic" and more consistent in their habits. Their motto is invariably "give electrons away and never accept them." They form positively charged ions. The gain of extra electrons is not in their line. Such is the rigid rule of behaviour of the metallic elements.

This is the basic difference between metals and nonmetals.

However, meticulous chemists have found exceptions even to this very strict rule. There are inconsistent characters even among the metals. Two (so far!), only two metals have displayed "unmetallic" features. Astatine and rhenium (the inhabitants of the 85th and 75th boxes of the Mendeleyev Table) are known to form negative univalent ions. This fact is like a black mark for the surprisingly purposeful family of metals...

Now, generally speaking, which atoms part with their electrons more easily and which accept them more readily? Atoms which have few electrons on their outermost shell find it more convenient to give them away, and those which have many of them find it more profitable to complete their electron octets by acquiring them. The alkali metals have only a single electron on their outsides. These metals think nothing of parting

with it. Once they have done so they find the stable electron shell of the nearest inert gas on their outside. That is why the alkali metals are chemically the most active of all known metals. And the "very most active" among them is francium (box 87). The heavier an element is in its group, the larger its atom and the weaker the hold the nucleus has on its only outside electron.

The most furious in the kingdom of nonmetals is fluorine. It has seven electrons in its "outer sphere." All it needs for complete bliss is an eighth electron. And it grabs it greedily from almost any other element of the Periodic System; nothing can resist fluorine's mad onslaught.

The other nonmetals also accept electrons, some of them more, others less easily. And now we can understand why they are grouped mainly in the upper right-hand corner of the table: they have plenty of electrons on their outsides, and this is possible only in atoms near the ends of the periods.

### **Two More "Whys"**

Why are there so many metals and so few nonmetals on Earth? And why do metals resemble each other much more than nonmetals? Indeed, one is not likely to confuse, say, sulphur and phosphorus or iodine and carbon by their appearance. But even the expert eye cannot always distinguish between niobium and tantalum, potassium and sodium, or molybdenum and tungsten.

Transposition of terms does not change the sum. This is probably one of the most "rigid"

principles of arithmetic. But in chemistry, relative to the structure of atomic electron shells, this principle applies far from always. . .

All is good and well as long as we have to do with the elements of the second and third periods of the Periodic Table.

In each element of these periods the new electron goes into the outermost shell of the atom. An electron is added, and the properties of the new element are entirely different from those of its predecessor. Silicon does not resemble aluminium, sulphur has nothing in common with phosphorus. Metallic properties soon give way to non-metallic, because the more electrons the atom has in its outer shell, the less readily it parts with them.

But now we come to the fourth period. Potassium and calcium are first-rate metals. We expect them to be followed soon by nonmetals.

Not so fast! We are in for a disappointment, because beginning with scandium each added electron prefers the second-last shell to the outer one. "Transposition of terms. . ." But this transposition changes the "sum"—the sum of the properties of the elements.

The second-last shell is more conservative than the outer one, and it affects the chemical properties of the elements much less. Therefore, the difference between the elements is less pronounced.

Scandium "recalls", as it were, that its third electron shell is incomplete. It should contain 18 electrons but has only 10 so far. Potassium and calcium must have "forgotten" about this, and arranged their newly-added electrons in

their fourth shells. In scandium, justice is restored.

The second-last shell is gradually completed over a series of ten elements. The outer shell remains unchanged, with only two electrons in it. Such a small number of electrons in the outer shell of an atom is peculiar to metals. And that is why there are only metals in the scandium-zinc "span." Why should they accept electrons in their outer shell when forming compounds if they have only two electrons in it? It is much easier for them to give away these two electrons to the elements they react with. Besides, they do not object to borrowing additional electrons from their incomplete second-last shell. As a result, they can display various positive valences. For instance, manganese may be positively di-, tri-, tetra-, hexa-, and even heptavalent.

The same is observed in the subsequent periods of the Periodic Table.

That is why there are so many metals and why they are more like one another than the non-metals.

### **Inconsistencies**

Has anybody heard of hexavalent oxygen? Or heptavalent fluorine? No, nobody has ever heard of them.

We don't like to be pessimists but we can say quite confidently that chemistry will never know such ions of oxygen and fluorine.

There is no reason under the sun why these elements should shed such a large number of electrons when all they need is to acquire two or one to form a stable octet electron shell. That is



why very few compounds are known in which oxygen exhibits positive valence. For example, an oxide of the composition  $\text{F}_2\text{O}$  has been obtained where oxygen is positively bivalent. But this is exotics, as far as chemistry is concerned. Compounds of positively valent fluorine are also very rare.

One of the items of the "Big House Regulations" states that the highest positive valence of an element shall be equal to the number of the group it belongs to

Though oxygen and fluorine break this rule, they have been registered permanently in the sixth and seventh groups. Nor has anyone ever thought of moving them, because in all other respects the chemical behaviour of oxygen and fluorine does not differ from the way of life of their heavier neighbours on the other floors of the Big House.



Still, this is an inconsistency, one that chemists are well aware of; but they pay no attention, for it does no damage to the architecture of the Mendeleev Table.

Alas, there is yet another, more ponderous inconsistency.

In the Middle Ages miners sometimes came across strange ores, greatly resembling iron ores. But the trouble was that iron could never be extracted from them. The miners attributed their failures to the pranks of evil spirits—the noxious goblins called kobolds in German, and the old mocking devil Nick.

Later on it became clear, of course, that evil spirits had nothing to do with it. The ores did not contain iron, but two other metals that resemble it. In memory of these old delusions they were called cobalt and nickel.

Also in the Middle Ages the Spanish conquerors found a strange metallic substance on the banks of the River Platino del Pino in South America. This strange lustrous, heavy metal which would not dissolve in any acid, was named platinum. Three centuries later it was found that platinum occurs almost always together with five companions: ruthenium, rhodium, palladium, osmium, and iridium. These six rare metals are very difficult to distinguish from one another and the practically inseparable group became known as the platinum family.

There came the time to place them in the Big House.

Now you are all set to hear an amusing story of how involved this was and how scientists overcame all the difficulties one by one.



We are sorry to disappoint you, but it was all very simple. . .

### **Originality in Architecture**

Have you ever seen a house with all its bays or sections planned identically according to a type design, except for one which differs entirely from the rest, as if a different architect had made it?

It is not very likely that you have.

Well, the Big House is just such a curious structure. Mendeleev fashioned one of its sections quite uniquely. It may be added that he had to.

The section in question is the eighth group of the Periodic System. The elements in it are arranged in threes. Furthermore, they are not on each floor, but only in the long periods of the table. Iron, cobalt, and nickel are in one of them and the platinum metals, in the other two.

Mendeleev tried hard to find more suitable places for them. But he was finally obliged to add an eighth group to the Periodic Table.

Why an eighth? Simply because the last group before that was the seventh, the one with the halogens.

But that makes the group number purely formal.

A valence of plus eight in the eighth group is a rare exception rather than the rule. Only ruthenium and osmium try to conform, though they find it far from easy; their oxides,  $\text{RuO}_4$  and  $\text{OsO}_4$ , are unstable.

None of the other metals have ever reached such "heights," despite all the scientists' efforts to help them.

Let us try to solve this riddle together.

Note that the platinum metals participate in chemical reactions very reluctantly. That is why chemists now often use platinum laboratory ware for their experiments. Platinum and its companions are the "noble gases," as it were, among the metals. It is therefore not without reason that they have been called "noble" for ages. Note also that they occur in nature in the native, uncombined state.

Now take iron, for instance. Ordinary iron behaves chemically like a moderately active element. Pure iron is very stable.

(By the way, here is something to think about. Maybe many of the elements, not only metals, are highly resistant to chemical influences when extra pure.)

It is not the outermost, but the second-last electron shell in the atoms of the platinum metals that is responsible for their "nobility."

This shell lacks but a very few electrons to make a complete set of eighteen\*, an eighteen-electron shell being also a fairly stable structure. That is why the platinum metals are not inclined to give away electrons from this shell. Nor can they accept electrons, because they are metals, after all.

This "irresoluteness" of the platinum metals accounts for their peculiar behaviour.

Still, the eighth group does not fit very well into the logic of the Mendeleev Table. To eli-

\* The element palladium actually has a complete set of eighteen electrons in its second-last (*N*) shell, and no electrons in its outer (*O*) shell:—*Tr.*

minate this inconsistency chemists have suggested combining the eighth and zero groups into one.

The future will show whether this is the right thing to do.

### **Fourteen Twins**

They are called lanthanides. Such is their name because all of them—fourteen in all—are “lanthanum-like,” that is, resemble lanthanum and one another almost like so many drops of water. Because of this astonishing chemical similarity they are all situated in a single box, the box of lanthanum whose number in the table is 57.

Isn't this some terrible misunderstanding? Mendeleev himself and many other scientists reasoned that each element had a single quite definite place in the Periodic Table.

But here fourteen inhabitants of the system have crowded into the same box, all of them elements of the third group and of the sixth period.

Why not try sorting them out among the other groups?

Many chemists have tried, among them Mendeleev. They placed cerium in the fourth group, praseodymium in the fifth, neodymium in the sixth, and so on. But this distribution defied all logic. The main and secondary subgroups of the Mendeleev Table contain similar elements. But cerium had very little in common with zirconium, praseodymium and neodymium were strangers to niobium and molybdenum. Nor could the other rare-earth elements (such is the general name for lanthanum and the lanthanides) find relatives in the corresponding groups. On the other hand, they resembled each other like twin brothers.

When chemists were asked what boxes of the table to place the lanthanides in, they shrugged their shoulders in bewilderment. Indeed, what could they say when they did not know the reason for the astonishing similarity of the lanthanides?

But the explanation proved quite simple.

The Periodic System has curious groups of elements whose atoms have quite a peculiar constitution. The last electron added to form these atoms does not settle in their outermost, or even in their second-last shells, but penetrates, in conformance with strict physical laws, right through to the third-last shell.

They feel quite cosy there and have no inclination to abandon their places under any circumstances. They participate in chemical reactions only in very rare cases.

Now since all the lanthanides have three electrons in their outer shells, they are trivalent, as a rule.

Nor is it accidental that the number of lanthanides is fourteen, neither more nor less. This is because there are exactly fourteen vacancies in the third-last shell of their atoms, the one that is being filled.

That is why chemists found it possible to place all the lanthanides in one single box together with lanthanum.

## **The World of Metals and Its Paradoxes**

Over eighty of the elements in the Periodic System are metals. On the whole, they resemble

one another more than the nonmetals. And yet there is no end of surprises in the metal kingdom.

For instance, what colour are the different metals?

Metallurgists divide all metals into ferrous and nonferrous. The ferrous metals include iron and its alloys. All the rest are nonferrous metals, except for the noble ones, their "Majesties" Silver, Gold and Platinum and Co.

This is a very crude division and even the metals themselves object strongly to such lack of discrimination.

Each metal actually has its own particular hue. Its dark, dull, or silvery base always has a definite tint. Scientists have become convinced of this by studying metals in the very pure state. Many of them when left in the air, become coated sooner or later with a very thin film of oxide which masks their true colour. But the pure metals give a very wide range of colours. The observant eye can discern metals with bluish, greenish-blue and greenish shades, with a reddish or yellowish play of colours, dark-grey like sea water on a cloudy autumn day, and shiny silvery ones which reflect solar rays like a mirror.

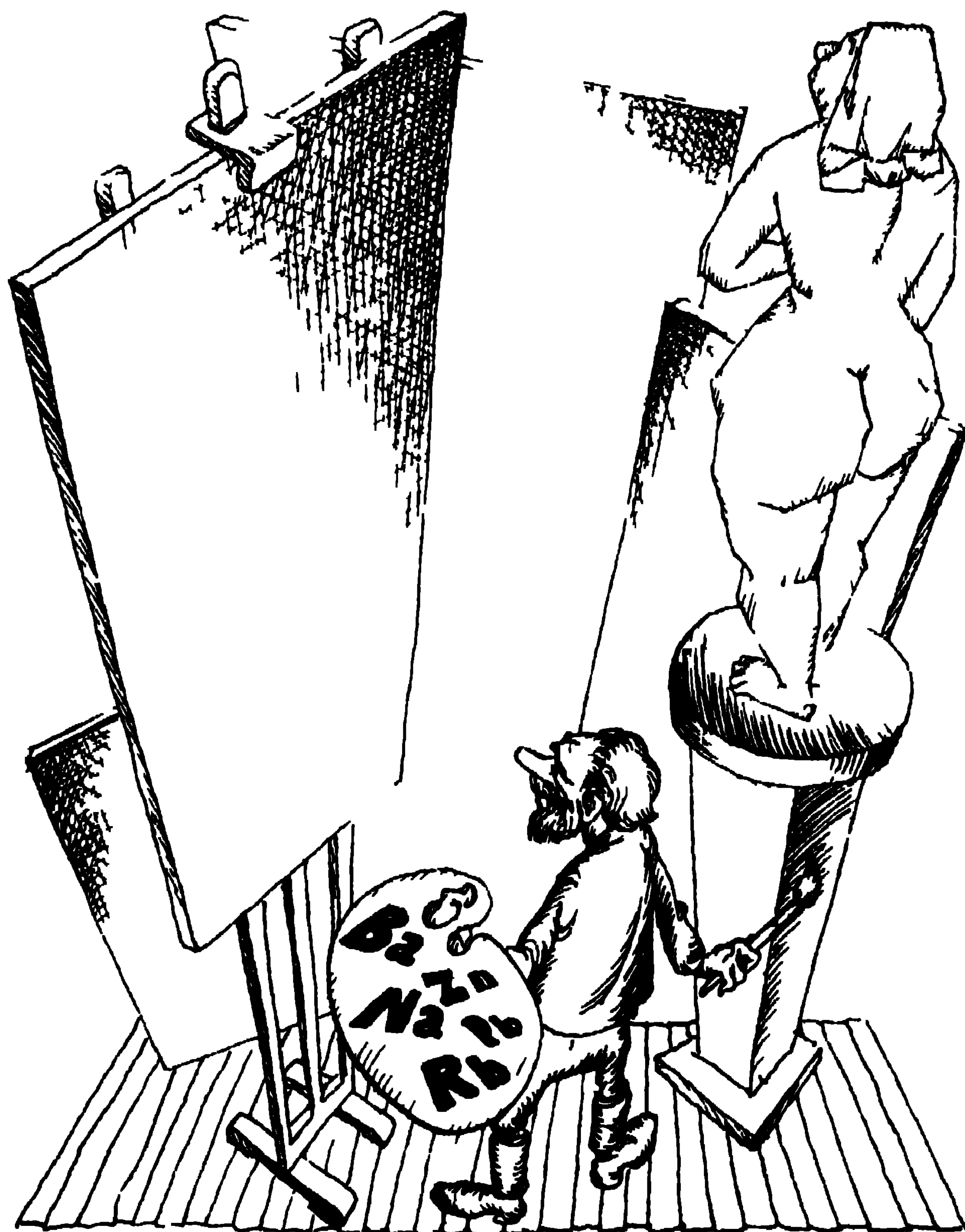
The colour of a metal depends on many factors. Among others, it depends upon the method of its production. A metal obtained by sintering has a different appearance from the same metal poured into an ingot.

If we compare metals by weight, we can distinguish light, medium and heavy ones.

These "weight classes" have their record holders.

Lithium, sodium, and potassium do not sink in

water, because they are lighter than water. For example, the density of lithium is almost half that of water which equals unity. Were lithium not so active an element it would be an excellent material for a great variety of purposes. Imagine a ship or an automobile made entirely of lithium.



Unfortunately, chemistry bans this attractive idea.

The "heavyweight champion" among the metals is osmium. One cubic centimetre of this noble metal weighs 22.6 grams. To balance one cube of osmium we would have to put on the other tray, say, three cubes of copper, two cubes of lead or four cubes of yttrium. The "performance" of osmium's closest neighbours, namely, platinum and iridium, is almost as high. The noble metals are also the heaviest metals.

The hardness of metals has become proverbial. If a man is always composed and cool-headed, we say he has "iron nerves." But in the world of metals the situation is different.

Here iron is hardly a model of hardness. The hardness champion is chromium which is just slightly inferior to diamond. By the way, paradoxical though it sounds, the hardest chemical elements are not metals at all. At the top of the conventional hardness scale stand diamond (a form of carbon) and crystalline boron. Iron should rather be classed as a soft metal; it is only half as hard as chromium. And as to the lightweights, the alkali metals, they are as soft as wax.

### **Liquid Metals and a Gaseous (!) Metal**

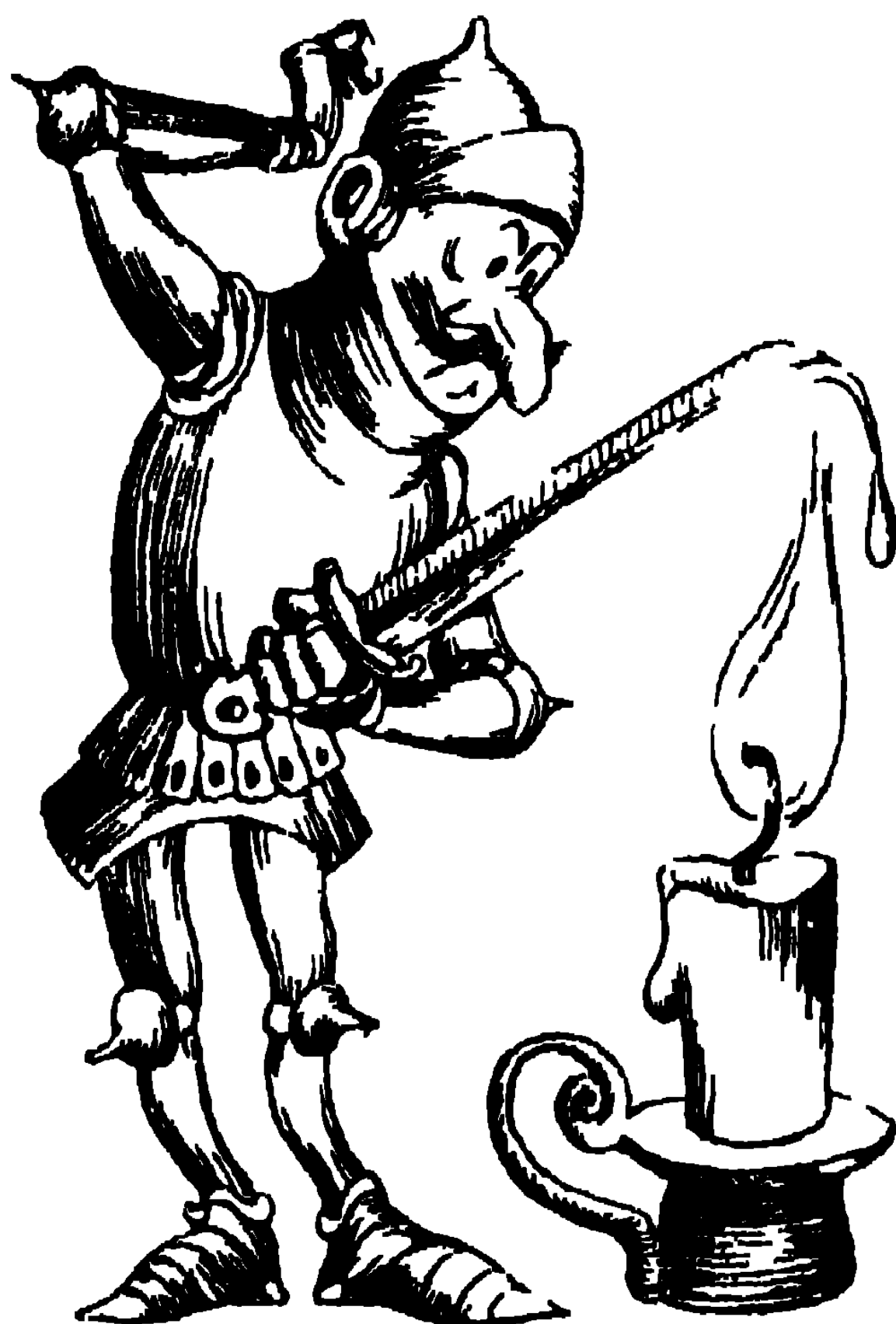
All the metals are solids, harder or softer. Such is the general rule. But there are exceptions.

Some metals are more like liquids. A chip of gallium or cesium melts on your palm, because the melting point of these metals is just below thirty degrees Celsius (86°F). Francium, which



has not been prepared as the pure metal so far, would melt at room temperature. Mercury is a classical example of a liquid metal which everybody knows. It freezes at minus  $39^{\circ}\text{C}$  ( $-38.2^{\circ}\text{F}$ ), which makes it eligible for various kinds of thermometers.

An important rival to mercury in this respect is gallium, and here is why Mercury boils at the comparatively low temperature of about  $300^{\circ}\text{C}$  ( $572^{\circ}\text{F}$ ) This makes mercury thermometers useless for measuring high temperatures But it takes a temperature of  $2000^{\circ}\text{C}$  ( $3670^{\circ}\text{F}$ ) to turn gallium into a vapour. Not a single metal can remain in the liquid state for so long, i e , has such a large interval between its melting and boiling points, as gallium. This makes gallium an excellent material for high-temperature thermometers





One more thing, and this is quite remarkable. Scientists have proved theoretically that if there existed a heavy analogue of mercury (an element with a very large atomic number, an inhabitant of the imaginary seventh floor—eighth period—of the Big House, unknown on Earth) its natural state at ordinary conditions would be gaseous. A gas possessing the chemical properties of a metal! Will scientists ever have such a unique element to study?

A lead wire can be melted in a match flame. Tin foil immediately changes into a drop of liquid tin if thrown into a fire. But to liquefy tungsten, tantalum or rhenium, the temperature has to be raised above  $3000^{\circ}\text{C}$  (about  $5500^{\circ}\text{F}$ ). These metals are harder to melt than any of the others. That is why the filaments of incandescent electric light bulbs are made of tungsten and rhenium. The boiling point of some metals are really tremendous. For instance, hafnium begins to boil at  $5400^{\circ}$  (almost  $9800^{\circ}\text{F}$ ) (!), almost the temperature of the Sun's surface.

### **Unusual Compounds**

What was the first chemical compound deliberately produced by man?

The history of science can give no definite answer to this question.

Let us take the liberty to make our own assumptions on this point. The first substance which man prepared, knowing beforehand what he wanted to obtain, was a compound of two metals, copper and tin. We have deliberately avoided using the word "chemical," because the compound of cop-

per and tin (commonly known as bronze) is an unusual one. It is called an alloy.

The ancients first learned to smelt metals from their ores and only afterwards to fuse them with each other.

Thus, at the dawn of civilization appeared the first seeds of a branch of the future science of chemistry, now called metal chemistry. The structure of compounds of metals and nonmetals usually depends on the valence of the elements contained in them. For example, the molecule of common salt contains positively univalent sodium and negatively univalent chlorine. In the ammonia molecule  $\text{NH}_3$  negatively trivalent nitrogen is linked with three positively univalent hydrogen atoms. The chemical compounds of metals with one another (called intermetallic compounds) usually do not obey the laws of valence, and their composition bears no relation to the valence of the reacting elements. For this reason the formulas of intermetallic compounds look rather strange, for instance,  $\text{MgZn}_5$ ,  $\text{KCd}_7$ ,  $\text{NaZn}_{12}$ , etc. The same pair of metals can often give several intermetallic compounds: for instance, sodium and tin form nine different combinations.

Metals interact with one another in the molten state, as a rule. But metals do not always form chemical compounds with each other when fused. Sometimes one metal simply dissolves in the other. The result is a homogeneous mixture of indefinite composition which cannot be expressed by any distinct chemical formula. Such a mixture is called a solid solution.

Alloys are legion; nobody has ever taken the trouble to count up even approximately how many

of them are known already and how many can be obtained, in general. As in the case of organic compounds, this figure would probably also run into the millions.

There are some alloys which consist of no less than a dozen metals, and each new addition has a specific effect on their properties. There are many alloys which contain only two metals, these being called bimetallic, but their properties depend on the proportion of their components. Some metals fuse very readily and in any proportion. Such are bronze and brass (an alloy of copper and zinc). Others, such as copper and tungsten, are reluctant to mix under any conditions. Still, scientists have succeeded in making an alloy of them though in an unusual manner, by what is known as powder metallurgy, that is, by sintering copper and tungsten powders under pressure

Some alloys are liquids at room temperature; others are very resistant to high temperatures. The latter are used in large quantities in space engineering. Finally, there are alloys which do not yield even when attacked by the strongest chemical agents, and alloys which are almost as hard as diamond. . .

### **The First "Electronic Computer" in Chemistry**

Electronic computers can do many things. They have been taught to play chess, to forecast the weather, to find out what is happening in the depths of distant stars, to carry out calculations involving unthinkable difficulties. All one has to know is how to assign their programme of operations. Electronic computers are now finding more

and more usage in chemistry too. Great automatic plants are controlled by these machines. With their aid, investigators learn everything about numerous chemical processes before putting them into practice. . .

But chemists have at their disposal a rather unusual "electronic computer." It was invented about a hundred years ago before the term electronic computer ever appeared in the languages of the world.

This remarkable machine is the Periodic System of Elements.

It enables scientists to do what even the most daring investigators would not risk doing before. The Periodic System made it possible to predict the existence of elements yet unknown, undiscovered even in the laboratory. And not only to predict them, but even to describe their properties. It could tell whether they would be metals or non-metals, heavy like lead, or light like sodium, and in what terrestrial ores and minerals the unknown elements were to be sought. The answers to all these questions were supplied by the "electronic computer" invented by Mendeleev.

In 1875 the French scientist Paul Emile Lecoq de Boisbaudran made an important report to his colleagues. He had succeeded in detecting an admixture of a new element in a zinc ore, a tiny grain weighing not more than a gram. Being an experienced investigator, he studied the properties of gallium (such was the name of the "newborn" element) in all their aspects, and wrote a paper about them.

Some time passed and the post brought de Boisbaudran an envelope bearing a St. Petersburg

postmark. In the brief letter the French chemist read that his correspondent agreed in full with his results, except for one detail: the specific gravity of gallium should be 5.9 instead of 4.7.

The letter was signed: D. Mendeleev.

Lecoq de Boisbaudran was worried. Had the Russian titan of chemistry anticipated him in the discovery of the new element?

No, Mendeleev had not had gallium in his hands. He had simply made efficient use of the Periodic System. Mendeleev had long since known that sooner or later an unknown element would be found to take the place in the table, which was now occupied by gallium. He had given it the preliminary name of eka-aluminium and had predicted its chemical nature very accurately, knowing the properties of its neighbours in the Periodic Table...

So Mendeleev became the first "programmer" in chemistry. He predicted almost a dozen other then unknown elements, and described their properties more or less completely. Their present names are: scandium, germanium, polonium, astatine, hafnium, rhenium, technetium, francium, radium, actinium, and protactinium. Most of them had actually been discovered by 1925.

### **A Hitch in the "Electronic Computer"**

Physics and chemistry had made tremendous progress by the twenties of our century. In a matter of two decades these sciences had scored no less achievements than throughout the preceding history of mankind.

But the discovery of new elements suddenly

came to a standstill. There remained several "blank" spaces in the Periodic Table which had to be filled. These were the boxes corresponding to the atomic numbers 43, 61, 85, and 87.

What strange elements were these which refused flatly to settle in the Periodic Table?

Stranger No. 1. An element of Group Seven with the atomic number 43, situated between manganese and rhenium, and probably similar in properties to these elements. It was to be sought in manganese ores

Stranger No. 2. A companion of the rare-earth elements resembling them in all aspects. Atomic number 61.

Stranger No. 3. The heaviest halogen, iodine's elder brother. It could be a great surprise to chemists, for it was not impossible that its properties would be weakly metallic. Halogen and metal—what a splendid example of a two-faced element! Flat 85 of the Big House was kept in readiness for it.

Stranger No. 4. Now this is an interesting element. The most furious, the most active metal, and it would melt if just held on the palm of your hand. The heaviest of the alkali metals. Its atomic number is 87.

Scientists compiled very detailed files on the mysterious strangers. Sherlock Holmes could detect a criminal by the ashes of a cigar he had smoked, by specks of clay adhering to his shoe leather. But his methods were nil compared to the delicate methods of chemists who had learned to identify the minutest amounts of unknown substances.

The clever detective was always lucky. The



chemists were not. All their efforts to find the mysterious strangers and install them in their flats ended in failure.

The strangers were sought everywhere. in cigar ashes and in plant remains; in the rarest and most exotic minerals, the pride of mineralogical museums; in the waters of the seas and oceans. All in vain!

On the shelf of unsolved problems there appeared a new brief entitled "The Case of the Mysterious Disappearance of the Chemical Elements 43, 61, 85 and 87." A "disheartening case," some crime investigators might have called it.

Could nature have been up to the unsuspected trick of eliminating these elements from the list of simple substances existing on our planet. Could it be another of her strange whims? . . .

Indeed, it looked like magic. They say that miracles don't happen, but for reasons unknown the four flats of the Big House remained vacant.

They were filled only after the scientists learned to make chemical elements artificially.

## **How to Change One Element into Another**

Innumerable chemical reactions occur in the world around us. They all obey the authority of electron-shell chemistry. An atom may gain electrons or may lose them, becoming a negatively or a positively charged ion. An atom can combine with hundreds and thousands of others to form a giant molecule. But it always remains the carrier of the properties of the same element. Carbon forms over three million compounds, but in each of them, be it carbon dioxide  $\text{CO}_2$  or the

most complicated antibiotic, carbon remains carbon.

Changing an element into another involves rearranging its atomic nuclei to alter their charge.

To bring about chemical processes chemists make use of high temperatures and pressures and of catalysts, substances which accelerate reactions when added in small amounts.

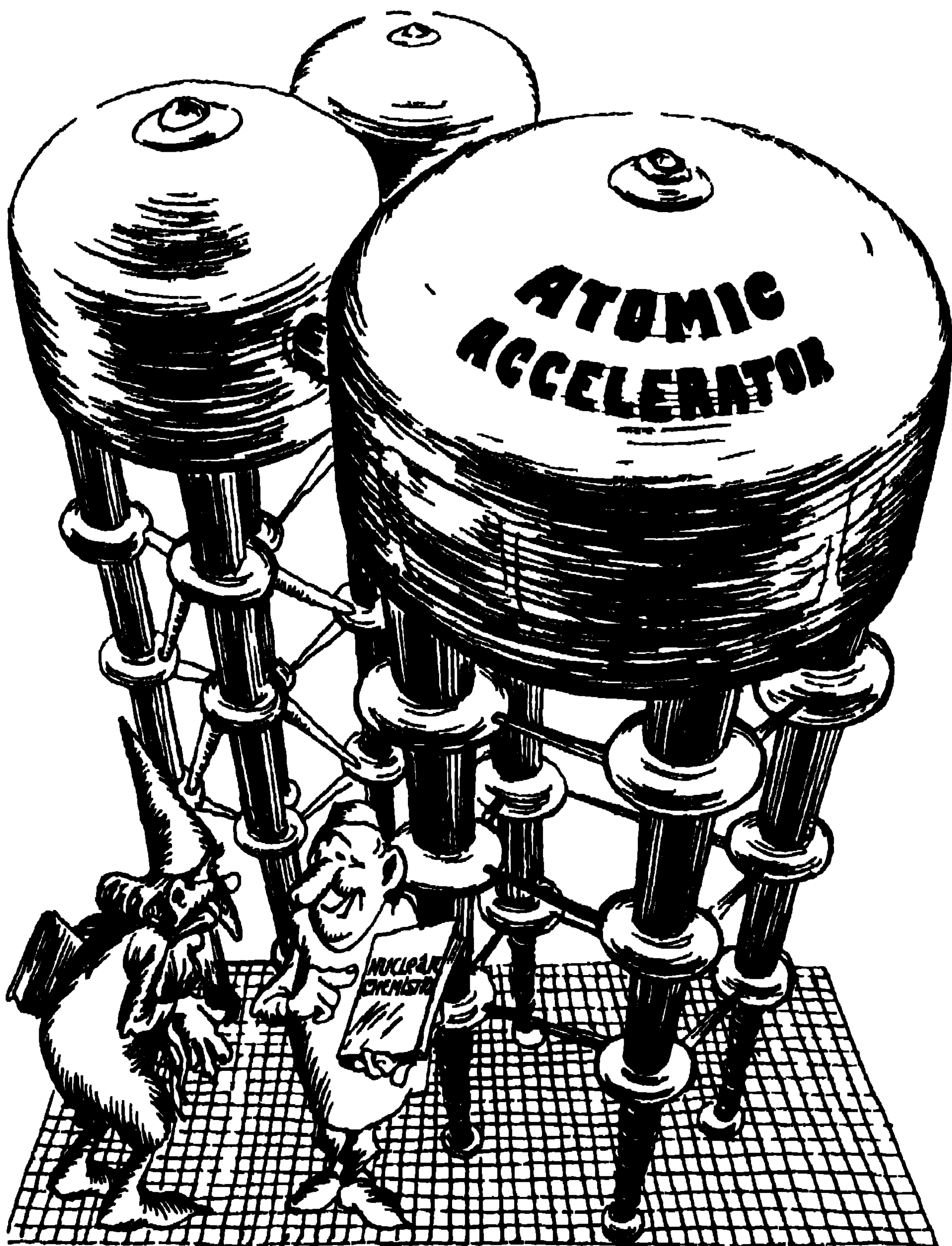
Temperatures of thousands of degrees and pressures of hundreds of thousands of atmospheres fail to rearrange the atomic nucleus. One element cannot be changed into another in this way.

But it can be done by the methods of a new science called nuclear chemistry. The "temperatures and pressures" of nuclear chemistry are protons and neutrons, nuclei of heavy hydrogen isotopes (deuterons) and nuclei of helium atoms (alpha-particles), and finally, ions of the lighter elements of the Mendeleyev Table, boron and oxygen, neon and argon. Its chemical equipment includes nuclear reactors in which certain bombarding particles are formed, and accelerators, complex apparatus for speeding up the particles to immense velocities. To penetrate the atomic nucleus the missile particle must possess a high energy (especially if it is positively charged); this makes it easier to overcome the repulsive action of the nuclear charge. Nuclear chemistry has its own system of symbols, but the equations of its reactions resemble "conventional" chemical equations.

It was due to nuclear chemistry that the blank spaces in the Mendeleyev Table were finally filled.



The Greek word "technetos" meaning "artificial" went into the name of the first element prepared artificially by man. In late 1936 a beam of fast deuterons accelerated in a cyclotron crashed down on a molybdenum plate. The swift deuterons cut through the electron shells like a knife through butter and reached the nucleus. On hit-



ting the nucleus each deuteron, consisting of a proton and a neutron decomposed, the neutron glancing off at an angle and the proton being captured by the nucleus. This increased the nuclear charge by one unit, and molybdenum, which occupies Box No. 42 changed into its right-hand neighbour, element No. 43.

Like in ordinary chemistry, where the same compound can be obtained by various routes, so in nuclear chemistry the same elements can be prepared artificially by means of different reactions.

People learned to make technetium in kilogram quantities at the most wonderful factory in the world. This factory is the nuclear reactor, where energy is produced by slow neutrons splitting uranium nuclei.

The uranium nuclei break up into different fragments, each nucleus producing two fragments. These are atomic nuclei of elements situated in the centre of the Mendeleyev Table. On fission uranium gives birth to elements which occupy more than 30 boxes of the Periodic Table, ranging from No. 30 to No. 64, and including technetium, and another of the stranger elements, which had been sought in vain for decades in the Earth's crust. This was promethium, the inhabitant of Box No. 61.

Nuclear chemistry gave scientists elements heavier than uranium. Besides fragments, the fission of uranium nuclei gives rise to a large number of neutrons which can be taken up by unsplit nuclei. Thus it becomes possible to synthesize elements with the atomic numbers 93, 94, and so forth, known as the transuranium elements.

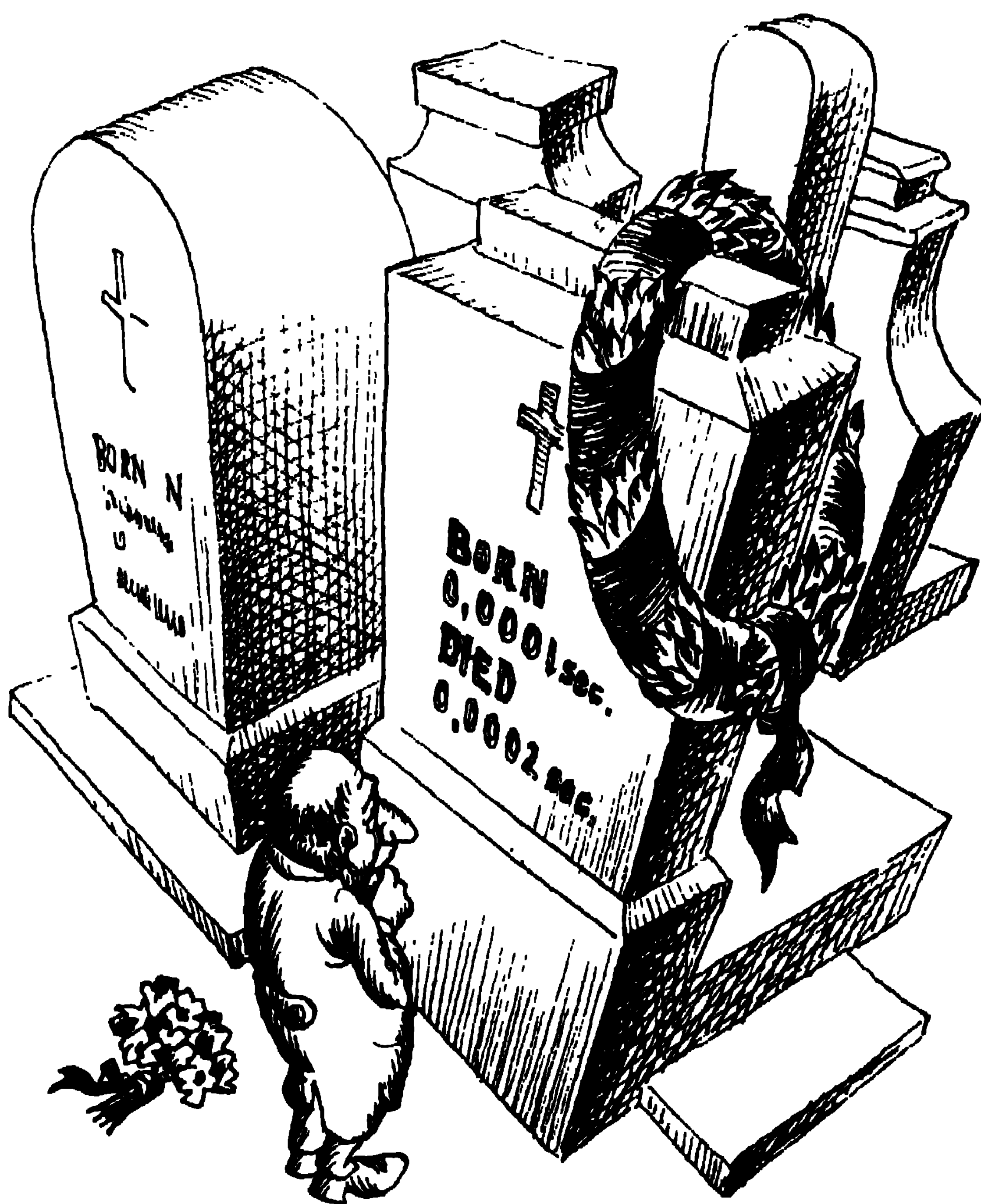
Nuclear chemistry knows many methods of producing these elements. At present, 12 transuranium elements are known, namely: neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, lawrencium, and kurchatovium, the latter being the heaviest transuranium element synthesized just recently (in 1964) by a group of Soviet physicists headed by P. Flerov. One of the transuranium elements, that having the atomic number 102, has not yet been named.

Imagine the surprise of a mason who one day just finished laying the bricks for a new storey of a house, and on the next found that all his work had disappeared. Such is precisely the predicament of investigators studying the chemical properties of the heavy transuranium elements. These elements are very unstable, their lifetime being a matter of minutes or even seconds. When working with ordinary elements the chemist is not pressed for time. But when he lays his hand on the short-lived representatives of the Periodic Table, especially the heavy transuranium elements, each minute of the investigation is "worth its weight in gold." Not only are the objects being studied likely to disappear any second, the amounts at the chemist's disposal are very scanty, sometimes literally a few atoms.

This makes it necessary to employ special methods of investigation. They are governed by a new young branch of chemistry known as radiochemistry, the chemistry of the radioactive elements.

## Mortality and Immortality in the World of Elements

There came a time when chemists became archeologists in a way. They learned to measure the age of various minerals in the Earth's crust, much like an archeologist determines how many cen-



turies ago a bronze adornment or an earthenware vessel was made.

Some minerals were found to be more than four and a half billion years old. They are as old as the planet Earth itself. But minerals are chemical compounds. They consist of elements. Therefore the elements are practically immortal.

Isn't it absurd to ask whether an element can die? Death is the sad fate of living creatures

No, this question is not so pointless as it seems at first glance.

There is a physical phenomenon called radioactivity. It consists in elements (rather, atomic nuclei) decaying spontaneously. Some nuclei emit electrons from their depths. Others throw up what are known as alpha-particles (helium nuclei). Still others break up into two approximately equal halves, this process being known as spontaneous fission.

Are all the elements radioactive? No, not all, but mainly those at the end of the Periodic System, starting from polonium.

In decaying, a radioactive element does not vanish altogether. It changes into another. The chain of radioactive transformations may be very long.

For example, thorium and uranium finally change into stable lead. But along their route a good dozen of radioactive elements are born and perish.

Radioactive elements possess different vitalities. Some of them may exist tens of billions of years before vanishing entirely. The lifetime of others is a matter of minutes or even seconds. Scientists assess the vitality of radioactive ele-

ments by means of a special quantity, called the half-life period or just half-life. During this period any quantity of the radioactive element taken decays to exactly half of its initial weight.

The half-lives of uranium and thorium are several billion years each.

It is entirely different with the elements that come before them in the Periodic Table, protactinium, actinium, radium and francium, radon, astatine, and polonium. Their lifetimes are much shorter, not more than a hundred thousand years in any case. And this brings up an unexpected puzzle.

How is it that these short lived elements still exist on Earth seeing that our planet is something like 5 billion years old? . . . This almost unimaginable time period should have been long enough for radium, actinium, and the other elements of their group to vanish a hundred times over.

Still, they do exist and have been concealed in terrestrial minerals for ages. . . It is as if nature has some elixir at its disposal which keeps them from perishing.

No, this is not the case. It is simply that they keep reappearing, because they are fed by an inexhaustible source, the terrestrial reserves of uranium and thorium. As long as these radioactive "patriarchs" keep travelling down their long and complex path of transformations, ultimately to form stable lead, they must continue changing into the intermediate elements. Thus, among the chemical elements we can distinguish two large groups, namely, the primary and the secondary elements.

The primary elements are all the nonradioac-



tive elements and uranium and thorium whose half-life periods are greater than the Earth's age. They witnessed the formation of the solar system.

All the rest are secondary elements.

Still, there will come a time when the Periodic System will find itself lacking several elements. These will be uranium and thorium, the eternal source of secondary elements which are, however, eternal only relatively. At some future time they will also disappear from the face of the Earth, in a matter of a few hundred billion years. And together with them will vanish the products of their radioactive transformations

### **One, Two, Three, Many...**

That was about what the counting abilities of primeval man amounted to. His mathematical apparatus included only two quantitative magnitudes, namely, "much," and "little."

People used much the same criterion about a hundred years ago when they tried to estimate the amounts of the separate elements our planet had stored away in its "granaries."

For example, lead, zinc, and silver had found wide usage in practice; there was much of them. Hence, these elements were considered abundant. But the rare earths (lanthanides) were rare because they were hardly ever encountered on Earth. There was little of them. See how easy it was to reason only a century ago.

The first inspectors of the chemical element storehouses had an easy job to do. Our contemporaries laugh to think of their "activities."



And how can they help laughing since they can now state exactly how much there is of everything! If they can even tell how many atoms of each element there are in the Earth's crust. They know for certain that the notorious rare earths are just slightly less abundant in the minerals of our planet than lead, zinc, and silver all taken together.

Scrupulous "accounting" of the reserves of chemical elements started with a scientific feat accomplished by the American scientist Clark. He performed more than 5500 chemical analyses of a great variety of minerals from the tropics and from the tundra, of all kinds of water from lakes in the depths of the wilderness and from the Pacific Ocean. He studied samples of various soils from all parts of the world.

This titanic work took him twenty years. Thanks to Clark and other scientists mankind got a quite distinct idea of the abundance of different elements on Earth.

So was born the science of geochemistry. It told wonderful stories such as had never before been known to man.

It appeared that the first 26 representatives of the Mendeleev Table, from hydrogen to iron, form practically the entire crust of the Earth. They constitute 99.7 per cent of its weight, leaving only a "miserly" three tenths of per cent for all the other 67 elements occurring in nature.

Now what is there the most of on Earth?

Neither iron, nor copper, nor tin, though man has been using them for thousands of years and the supply of these metals seemed immense, even

inexhaustible. The most abundant element is oxygen. If we place all the Earth's resources of oxygen on one pan of an imaginary pair of scales and all the rest of the elements on the other, the scales will strike an almost perfect balance. Almost half of the Earth's crust is oxygen. It is everywhere: in water, in the atmosphere, in an enormous number of rocks, in any animal and plant, and everywhere it plays a very important part.

One quarter of the Earth's "firmament" is silicon. It is the ultimate foundation of inorganic nature.

Further, the elements of the Earth arrange themselves in the following order of abundance: aluminium, 7.4 per cent; iron, 4.2 per cent; calcium, 3.3 per cent; sodium, 2.4 per cent; potassium and magnesium, 2.35 per cent each; hydrogen, 1.0 per cent; and titanium, 0.6 per cent.

Such are the ten most abundant chemical elements on our planet.

But what is there the least of on Earth?

There is very little gold, platinum and platinum metals. That is why they are valued so highly.

But it is a curious paradox that gold was the first of the metals to become known to man. Platinum was discovered before oxygen, silicon or aluminium had ever been heard of.

The noble metals possess a unique feature. They do not occur in nature as compounds but in the native state. No effort is required to smelt them from their ores, that is why they were found on Earth, precisely found, so very long ago.

However, these metals do not "take the cake"



for rarity. This lamentable prize goes rather to the secondary radioactive elements.

We could rightly call them ghost elements.

The geochemists tell us that the amount of polonium on Earth totals only 9600 tons; the amount of radon is still smaller, 260 tons; there is 26 thousand tons of actinium. Radium and protactinium are veritable giants among the ghosts: they total about 100 million tons, but compared to gold and platinum this is a very small quantity. As to astatine and francium, they can hardly be classed even as ghosts, because they are still less material. The terrestrial reserves of astatine and francium are measured, ridiculous though it sounds, in milligrams.

The name of the rarest element on Earth is

astatine (69 milligrams in all of the Earth's crust) No further comments are necessary.

The first transuranium elements, neptunium and plutonium, have also been found to exist on Earth. They are born in nature as a result of very rare nuclear reactions between uranium and free neutrons. These ghosts can "boast" of hundreds and thousands of tons. But as to promethium and technetium, which are also due to uranium (the latter is capable of spontaneous fission, with its nuclei breaking up into two approximately equal fragments), there is nothing that can be said of them. Scientists have found hardly perceptible traces of technetium, and are still looking for promethium in uranium minerals. The balance has yet to be invented on which the Earth's "reserves" of promethium and technetium could be weighed.

### **Has Nature Been Just?**

Today scientists say that all the chemical elements known to nature can be detected in any mineral sample. All without exception. Of course their proportion varies immensely. But why is there so much of some and so little of others?

In the Periodic System all the elements have equal rights. Each occupies its own definite place. But when it comes to the terrestrial reserves of the element, these equal rights vanish into thin air.

The light elements of the Mendeleev Table, its first thirty or so representatives, at any rate, constitute the bulk of the Earth's crust. But there is no equality among them either. Some are more abundant, others less. For instance, boron, beryl-

lithium and scandium are among the very rare elements.

Since the Earth has been in existence there has been something of a "revision" of the supplies of its elements. A considerable amount of uranium and thorium has disappeared owing to their radioactivity. A large amount of the noble gases and hydrogen has been lost to outer space. But the general picture has not changed.

The scientists of our days write that the abundance of the chemical elements in the Earth's crust decreases regularly from the light elements to the medium-weight ones and then to the heavy ones. This isn't always the case. For example, there is much more heavy lead on Earth than many of the light representatives of the Mendeleev Table. Why so? Why not equal amounts of all? Has not nature been unjust in "accumulating" some of the elements and not attending to the supplies of others?

No, there are laws according to which there is bound to be a great deal of some of the elements and little of the others. To be quite honest about it, we do not know these laws as yet, and content ourselves with assumptions.

You see, the chemical elements have not always existed. The universe is so constituted that there is always a gigantic process of formation or synthesis of elements going on in various parts of it, a process so great that there is nothing it can be compared to. The cosmic nuclear reactors, the cosmic accelerators are the stars. Chemical elements are always being "cooked" in the depths of some of them.

Unheard of temperatures, unimaginable pres-

tures reign there. The basic laws are those of nuclear chemistry, the rules—nuclear chemical reactions transforming one element into another, the light elements into heavy ones. And such are these laws that some elements form more easily and in greater quantities while others form with greater difficulty and therefore in smaller proportions.

It all depends on the stability of the different atomic nuclei. In respect to this nuclear chemistry has a quite definite opinion. The nuclei of light-element isotopes contain almost equal numbers of protons and neutrons. Here these elementary particles form very stable structures. That is why the light nuclei are easier to synthesize. In general, nature tends to create systems of the highest possible stability. They are easier to synthesize but participate less readily in nuclear reactions resulting in nuclei with larger charges. Nuclei of the latter kind contain considerably more neutrons than protons, and therefore nuclei of medium and heavy mass have no very great stability to boast of. They are more subject to the rule of chance, more inclined to change, and are therefore incapable of accumulating in very large quantities.

According to the laws of nuclear chemistry the higher the charge on the nuclei, the more difficult such nuclei are to synthesize, and therefore the less of them is formed.

The chemical composition of our Earth is like a silent replica, a voiceless reflection of the dynamics of the laws governing the process of origination of the elements. When scientists have learned these laws in full, we shall understand



why the different chemical elements differ so widely in abundance.

### **On the Track of False Suns**

In the eighties of the last century one of the chemical journals published a curious article. The author, hardly known to the scientific world, reported that he had succeeded in detecting two new elements at once. And he gave them the pompous names of kosmium and neokosmium. At that time the discovery of new elements had become quite a mass phenomenon. Some investigators did not even take the trouble to think up names for the "newborn" elements and denoted them by letters of the Greek alphabet.

It soon became apparent that the "discoverer" of kosmium and neokosmium had just been making fun of this discovery epidemic. The article was a kind of April-Fool joke. The author's name was Kosman.

... There are one hundred and four elements in the Periodic Table. One hundred and four actual discoveries of elements have been registered in the history of science. Besides this list, there is another one, incomparably longer, including several hundred names. Such is the "church calendar" of stillborn elements, those that came to life as a result of delusions, experimental errors, and sometimes simply carelessness on the part of investigators.

Long and thorny was the path of the discoverers of new elements, like a path through a thicket which keeps losing itself among narrow crevices. . . Next to it ran another path, a beaten track.



But the latter was the track of false suns, of false discoveries of chemical elements.

And oh, the number of queer things and paradoxes encountered on this track! The Kosman case was literally a drop in the ocean.

The Englishman Crookes isolated from yttrium a host of new simple substances which he called meta-elements. Actually they were simply mixtures of long known elements.

Swienne, a German scientist, sought the transuranium elements in samples of that was thought to be cosmic dust collected among the glaciers of Greenland by the famous polar explorer Norden-skjöld. And he hurried to report that he had succeeded in finding an element with the atomic number 108 in the dust. . . The truth was not long



in striking back. The ill-starred scientist had simply been under the illusion of an incorrect theoretical idea.

One cannot help recalling the Englishman Freehand who organized a special expedition to Palestine to "fish" for traces of elements No. 85 and No. 87 in the lifeless waters of the Dead Sea. Or the American Allison who, while scientists puzzled over the question why no heavy analogues of iodine and cesium could be found on Earth suddenly began discovering them everywhere. He detected them in all solutions and minerals checked by a new method he had worked out. The method turned out to be faulty. The analysis greatly fatigued the operator's eyes and caused illusions.

Even great men have not escaped errors on the track of false suns. The Italian Fermi thought that several transuranium elements at once appeared in uranium on bombardment with neutrons. Actually these were the fission fragments of uranium nuclei, elements of the middle of the Periodic System.

This notorious track persists even in our days. In 1958 a group of scientists in Stockholm synthesized a new element with the atomic number 102. It was named nobelium in honour of the inventor of dynamite. Soviet and American researchers disproved these results. And now the scientists say jestingly that all that is left of nobelium is its symbol "No." However, isotopes of the 102nd element have now been obtained quite authentically by other methods in the U.S.S.R. and the U.S.A.

## **The Fate of One of the Hundred and Four**

This is a little story about the fate of a chemical element.

Its address is Flat No. 92 and its name is uranium.

The name speaks for itself. Two of the greatest scientific discoveries of all times and all peoples are connected with uranium. These are the discovery of radioactivity and the discovery of the fission of heavy nuclei by neutrons. Uranium gave people the key to the mastery of nuclear energy. Uranium helped them to produce elements unknown in nature: the transuranium elements, technetium and promethium.

Historical documents witness that the biography of uranium began September 24, 1789.

All kinds of things have happened in the history of the discovery of the chemical elements. In some cases nobody knows who the discoverer was. On the other hand there are elements that have a rather bulky list of "discoverers". But uranium's "godfather" has been established quite definitely. This was the Berlin chemist Martin Klaproth, one of the founders of analytical chemistry. However, history has played a prank on him: Martin Heinrich Klaproth proved to be only one of the "godfathers" of our hero.

Pitchblende has been known to man for ages, and was considered an ore of zinc and iron. The sharp eye of the analyst Klaproth suspected an admixture of an unknown metal in it, and soon this suspicion became fact. The new element appeared as a black powder with a metallic lustre. It was named in honour of the planet Uranus,



discovered not long before by the English astronomer Herschel

After that for half a century nobody doubted the truth of Klaproth's discovery. Nobody even dared to question the work of Europe's foremost analytical chemist. The element uranium marched through the pages of chemical textbooks.

In 1843 this triumphant march was slowed down somewhat by the French chemist Eugene Peligot. He proved that what Klaproth had held in his hands was not the element uranium but only uranium oxide. Later unbiased historians wrote that Peligot could be considered the second "godfather" of the element.

But this did not exhaust the list of "godfathers" of uranium. The third was D. Mendeleev.

At first uranium just would not fit into the table. It was given a place in the third group between cadmium and tin, where indium is now situated. This place was allotted to uranium in accordance with its atomic weight, but not its properties. With respect to properties uranium looked like a casual stranger in the box allotted to it.

Mendeleev concluded that the atomic weight of uranium had been determined incorrectly and he increased it by 50 per cent. This put uranium in Group VI of the table and made it the last in the series of elements. Such was the third "bath" of uranium.

Soon experimenters showed that Mendeleev was right.

### **Where is Thy Place, Uranium!**

There are no elements in Mendeleev's System which have no place at all. There are elements with no definite place. Such, for instance, is the very first of them, hydrogen. Investigators are still at odds as to whether element No. 1 should be in the first, or in the seventh group of the Periodic Table.

Uranium is in much the same predicament.

But had not Mendeleev determined its position once and for all?

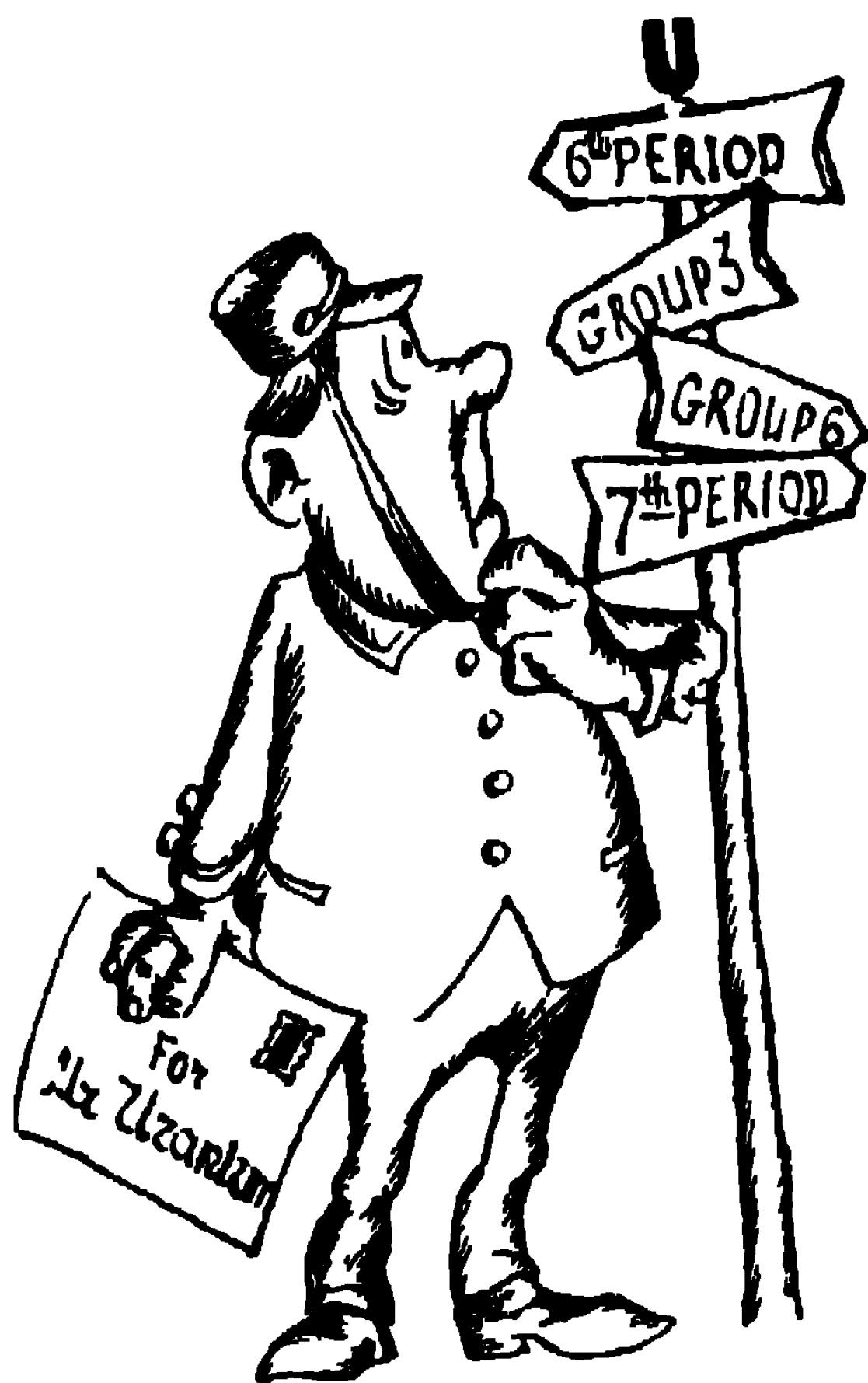
For decades no one questioned uranium's being in the sixth group of the Periodic Table as the heaviest member of the family including also chromium, molybdenum and tungsten, and its position seemed quite infallible.

But times changed, and uranium was no longer the last in the series of elements. A whole "co-

hort" of man-made transuranium elements ranged out at its right, and they all had to be placed in the Mendeleyev Table. What groups and what boxes were to be assigned to the transuranium elements? After much controversy a large number of scientists came to the conclusion that they should all be placed together in a single group and in a single box.

This decision did not fall from the moon, something of the sort had happened once before in the Periodic Table. The lanthanides, a total of 14 elements of the sixth period were all placed together with lanthanum in a single box of Group III.

The physicists had long since predicted that a similar phenomenon would recur in the next pe-



riod. They stated that a family of elements resembling the lanthanides should exist in the seventh period. The name of this family would be actinides, because it would begin right after actinium which is situated just below lanthanum in the table.

Hence, all the transuranium elements are members of this family. And not only they, but also uranium and its nearest left-hand neighbours, namely, protactinium and thorium. They all had to leave their old, familiar places in the sixth, fifth and fourth groups, and move into the third.

Almost one hundred years ago Mendeleev had moved uranium out of this group. Now it was back in it, but this time with "fuller rights." See what curious things may happen in the life of the Periodic System.

The physicists agreed to such a state of affairs, but not all the chemists, and not without reserve, because as regards properties uranium is just as much a stranger to Group III as it was in Mendeleev's time. Nor is the third group quite suitable for thorium and protactinium.

Where is thy place, uranium? It remains a point of controversy among scientists.

### **Little Stories from Archeology**

When did man first begin to use iron? The answer seems self-evident: when he learned to smelt iron from its ore. Historians have even established the approximate date of this great event, the date of the beginning of the "Iron Age" on Earth.

But actually the Iron Age started before the primeval metallurgists produced the first kilo-



gram of iron in the primitive blast furnace. Such was the conclusion drawn by the chemists armed with mighty methods of analysis.

The first pieces of iron used by our antecedents literally fell from the sky. What we call iron meteorites always contain nickel and cobalt besides iron. Now when analysing some of the most ancient iron tools chemists found them to contain iron's neighbours in the Mendeleev Table, namely, cobalt and nickel.

These metals are by no means always present in the iron ores on Earth.

Is this conclusion quite unquestionable? Not a hundred per cent, anyway. . . . The study of antiquity is a very difficult matter. But here one is very likely to come up against the unexpected.

Archeologists once sprang the following surprise on the historians of chemistry.

..In 1912, while carrying on excavations among ancient Roman ruins near Naples, Professor Günther of Oxford University found some glass mosaics of surprising beauty. The colour of the glass did not seem to have faded in two thousand years.

To establish the composition of the colouring matter used by the ancient Romans Gunther sent two samples of pale green glass to England where they fell into the hands of the chemist Maclay.

The analysis showed nothing unexpected, not to mention some impurity amounting to about one and a half per cent. But what this impurity was, Maclay could not say.

Chance saved the situation. It occurred to someone to see whether the impurity was radioactive. This was very fortunate, for the impurity

what the atomic number of the very last element would be.

About forty years ago the number 137 began to appear on the pages of special serious papers and books in physics. A prominent scientist even ventured to write a booklet entitled "The Magic Number 137."

Why is this number so remarkable?

The electron shell closest to the nucleus in atoms is not always the same distance from it. The radius of the shell becomes smaller with increasing nuclear charge. Therefore in the uranium atom this shell is much closer to the nucleus than, say, in potassium. There should finally come a moment when the nucleus and the shell closest to it become the same size. What would then happen to the electrons on this shell?

They would "fall" on the nucleus and be "swallowed up" by it. But penetration of a negative charge into the nucleus reduces the total positive charge of the nucleus by one unit. Hence, the atomic number of the newly formed element would be one unit smaller than that of the parent element.

And so we have come to the ultimate number of elements. The last flat in the Big House is No. 137.

Later, a little over ten years ago, the physicists discovered an error. More precise calculation showed that the electron would only crash down on a nucleus if its charge were about 150 or so.

See how bright the prospects of completing the Big House! How many new elements, how many unexpected discoveries await chemists! Over for-

ty future inhabitants await permission to move into the house founded by Mendeleyev.

Alas, today this is no more than a dream, an alluring but unrealizable fancy.

In calculating the atomic number of the last element scientists had omitted something very important. Not that they forgot about it—they just wanted to see what would be if...

If there were no radioactivity. If nuclei with very large charges were as stable as those of the numerous elements existing on the Earth.

Radioactivity is the absolute ruler of the elements heavier than bismuth. But it deals out long lifetimes to some and allows others to live only a few instants.

The hundred and fourth element, kurchatovium, has a half-life of only three-tenths of a second.

And what about the hundred and fifth, and the hundred and sixth? Their half-lives are in all probability still shorter. And not far off we come to the deadline where the nucleus of the new element breaks up almost before it is born. We would be lucky to get as far as the hundred and tenth...

Nature itself and its strict physical laws are to blame for the Mendeleyev Table being incomplete.

Still, how many a time has man conquered nature?

### **A Hymn to Modern Alchemists**

The ill-starred alchemists of the Middle Ages were tortured as ordained by the Spanish Inquisition and were burned at the stake.

Today's "nuclear" alchemists are quoted with deference and awarded Nobel Prizes.

The former believed in too much and knew not what they did. Their "theory" consisted of invocations, prayers, and blind faith in the magic properties of the mysterious philosopher's stone.

The latter believe neither in God nor in the Devil. They believe in the power of the human mind and in the boundless ingenuity of human hands. They recognize strict and sound physical theories consisting of a great deal of physics, a great deal of mathematics, and still more bold assumptions and hypotheses.

The alchemists of our day are trying to break through into the domain of the very heavy elements.

But will this not liken them to builders of castles in the air? We have just said that the life-times radioactivity assigned to elements with atomic numbers close to 110 were more than rigorous.

This is so, and yet not quite so. The great Danish physicist Niels Bohr once spoke of the good of "crazy" ideas. In his opinion only they are capable of revolutionizing current conceptions of the universe.

The creators of the super-heavy elements also have such ideas. Only we daresay these ideas are not much "crazier" than, say, those of the theory of relativity. They are thoroughly thought out, have a sound physical footing and have been checked by careful calculation.

The essence of these ideas is that there must be what one might call "stability islands" in the domain of highly charged nuclei. This does not

mean that the elements on them are not subject to radioactive decay, but just that they live longer than their neighbours, long enough not only to be synthesized, but to enable investigation of their chief properties.

One of these "islands" is the element with the atomic number 126.

So far all this is theory, and it is up to practice to prepare the hundred and twenty sixth.

The conventional methods of nuclear chemistry are obviously powerless. Neither neutrons, deuterons, alpha-particles, nor even the ions of the light elements—argon, neon, and oxygen—are of any use for this purpose, because there is no suitable target element. All the available elements are too far removed from the atomic number 126.

And so extraordinary methods must be invented. An original method now under discussion is that of bombarding uranium with uranium, of accelerating uranium ions with a special accelerator and hurling them at a uranium target.

What would be the result? The two uranium nuclei would merge into one monstrously complex nucleus. Uranium carries a charge of 92. Therefore the gigantic nucleus would have a charge of 184. It would not only be unable to exist, but would even have no right to. And so it would instantly break into two fragments with different masses and different charges. And it is quite probable that one of these would be a nucleus with a charge of 126. . .

Such is the idea. It would be a mistake not to believe that it will be realized sooner or later. For such is life. . .

## **On the Brink of the Unknown**

When it will happen nobody knows. But it certainly will. Man will score a great victory over nature, perhaps the greatest in all history.

He will learn to control radioactivity. He will be able to make the unstable elements stable, and vice versa, he will be able to make the most stable nuclei decay.

This hypothesis has not yet been taken up even by science fiction writers. And scientists also still shrug their shoulders in bewilderment: so far they can see no practical or theoretical ways of harnessing radioactive phenomena.

But we are confident that some day such ways will be found, though they may be as unfathomable to us as an atomic power station would be to a pithecanthrope, to use the apt expression of the author of a science fiction book.

Now let us suppose our wish has come true. The synthesis of super-heavy elements is no longer a problem. The scientist has at his disposal dozens of new inhabitants of the Big House. The chemists get down to studying them in an all-out drive.

And come face to face with the unexpected.

On second thought, "unexpected" is hardly the right word, because we already now know what to expect.

Can we predict the properties of, say, the element with the atomic number 126, mentioned above?

We can, and with no great difficulty.

Generally speaking, we could continue the Periodic System mentally as far as we liked. The



general physical principle of its structure is quite clear. A master-mind once demonstrated a table to one of the present authors, which contained a thousand elements. When asked, "Why a thousand and not two or ten thousand?", the "inventor" replied in embarrassment: "You see, the sheet was not large enough. . ."

But that was just another oddity. As to the hundred and twenty-sixth element, it can be said quite seriously and definitely that it will belong to a new family of elements, a very singular family, the like of which chemists have never seen.

The family will begin with element No. 121. And all its eighteen members will resemble one another much more, incomparably more than our old friends, the lanthanides. These strange inhabitants of the Big House will hardly differ from one another any more than the isotopes of one and the same element.

The reason is that the three outer atomic shells of all the elements of the family will be exactly the same; only the fourth-last shell will be filled gradually in the series. Could any perceptible difference in chemical properties be expected in such a case?

One of the stories of this book is entitled "Fourteen Twins." Now if we tried to describe the properties of the supposed family, we would have to do some hard thinking to find a title for it. Perhaps we might call it "The Eighteen Identical Elements" or "Eighteen Elements, and All as One." The word "twins" is "no go" in this case.

But since this book is not science fiction, we



shall defer concrete descriptions for better times. . .

Oh yes, how about the arrangement of these eighteen "absolutely identical" elements in the Periodic System?

To be honest, we are not very clear on this point ourselves. The more so, that there is still much controversy concerning the situation of the lanthanides and actinides, though this question is far more simple.

We wish you all a long life. But we do not think there will be any of our readers alive by the time the location of the eighteen elements in the Big House becomes a question of practical interest. But our readers' descendants, near or remote, will surely have to solve this problem.

### **Element Register**

There was once a rum fellow who when told about the stars, about their structure and why they emit light, exclaimed: "I can understand all that! But what I want to know is how the astronomers discovered the names of the different stars."

Stellar catalogues contain hundreds of thousands of "christened" heavenly bodies. But don't think that such pretty names as "Betelgeuse" or "Syrius" have been thought up for all the stars. Astronomers prefer to denote stars by a sort of code, a combination of letters and figures. If they did not there would be much confusion. But from the code the expert can easily locate the star and determine its spectral class.

The number of chemical elements is incompa-

rably smaller than of the stars. But here also their names often conceal thrilling stories of their discovery. And chemists who had discovered a new element were not infrequently at a loss to find a name for the "newborn."

It was important to think up a name which would be at least partly indicative of the element's properties. Such were business names, if you like. They could hardly be called romantic. Examples are hydrogen (the Greek for "producing water"), oxygen ("producing acid"), and phosphorus ("light-bringing"). These names record important properties of the elements.

Some elements were named after the planets of the solar system; such are selenium, and tellurium (from the Greek for Moon and Earth, respectively), uranium, neptunium and plutonium.

Other names are derived from mythology.

One of these is tantalum. Tantalus, the favourite son of Zeus, was cruelly punished for an offence against the gods. He had to stand up to his neck in water and above him hung branches with juicy aromatic fruit. But whenever he wanted to quench his thirst the water would flow away from him, and whenever he wanted to appease his hunger and stretched his hand out to pick a fruit, the branches would swing away from him. The sufferings experienced by chemists before their efforts to isolate the element tantalum from its ores were successful could be compared only to those of Zeus's son. . .

The names titanium and vanadium also stem from Greek mythology.

There are elements which were named in honour of various countries or continents, such as

germanium, gallium (from Gaul, the ancient name of France), polonium (Poland), scandium (Scandinavia), francium, ruthenium (Ruthenia is the Latin for Russia), europium and americium. Other elements were named after cities. These are: hafnium (Copenhagen), lutetium (from Lutetia, the Latin name for Paris), berkelium (in honour of the town of Berkely, U.S.A.), yttrium, terbium, erbium, and ytterbium (after Ytterby, a small town in Sweden where the mineral containing these elements was first discovered).

Finally, some elements were named to immortalize the names of great scientists: curium, fermium, einsteinium, mendelevium, and lawrencium.

The name of only a single artificially produced element, the hundred and second, has not yet been entered in its birth certificate.

There is still some controversy among scientists as to the origin of the names of the elements of antiquity, and nobody knows so far just why, say, sulphur is called sulphur, iron—iron, or tin—tin.

See how many curious things we find in the register of the chemical elements!

# **Snake with Its Tail in Its Mouth**



## **The Spirit of Chemical Science**

Almost everything on the Earth around us consists of chemical compounds, of a great variety of combinations of the chemical elements.

Only an insignificant part of terrestrial matter is in the form of elemental substances, namely: the noble gases, the platinum metals, carbon in its various forms, and that is about all.

Possibly, a very long time ago the clot of cosmic matter which finally became our planet, consisted all of only the atoms of almost 100 chemical elements. Hundreds, thousands, millions of years passed. Conditions changed. The atoms reacted with one another. The gigantic laboratory of nature began to operate. During its long evolution nature, the chemist, learned to prepare all kinds of substances, from the simple water molecule to infinitely complex proteins.

The evolution of the globe and of life on it is due largely to chemistry.

For the great diversity of chemical compounds owes its existence to processes called chemical reactions. They are the true spirit of chemical science, and its principal subject matter. It is impossible to estimate even approximately the number of chemical reactions that occur in the world, say, in the course of only one second.

For instance, for a person to pronounce the word "second" many chemical processes must occur in his brain. We speak, think, enjoy ourselves, or worry, and all these actions are backed by millions of chemical reactions. We never see these reactions, but there is also an immense number of chemical reactions that we do observe dai-

ly, just offhand, without stopping to think of them.

... We put a slice of lemon into a cup of strong tea and the tea becomes pale. We strike a match and a stick of wood bursts into flame and turns into charcoal.

These are all chemical reactions.

The primeval man who learned to light a fire was the first chemist. He accomplished at will the first chemical reaction, that of combustion. And this reaction is the most necessary, the most important in all the history of mankind.

It gave our distant ancestors the heat to warm their dwellings on cold days. In our time it has opened the way to outer space by propelling rockets weighing many tons into the sky. The legend of Prometheus who gave people fire is at the same time the legend of the first chemical reaction.

When simple or complex substances interact with each other, they usually let us know about it.

Drop a piece of zinc into a solution of sulphuric acid. Immediately gas bubbles begin to rise from it and after some time the metal disappears. The zinc dissolves in the acid, liberating hydrogen. You could see for yourself how it all happened.

Or light a lump of sulphur. It burns with a bluish flame and you can smell the asphyxiating odour of sulphur dioxide, the chemical compound which forms when sulphur combines with oxygen.

Moisten anhydrous copper sulphate  $\text{CuSO}_4$ , a white powder, with water, and it immediately turns blue. The salt combines with the water to



form crystals of blue vitriol  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ . Substances of this kind are called crystal hydrates.

Do you know what quenching of lime is? Water is poured on quicklime and the result is slaked lime  $\text{Ca}(\text{OH})_2$ . Though the substance does not change colour, it can easily be seen that a reaction has occurred, because when lime is quenched a great deal of heat is liberated.

The primary and invariable condition of all chemical reactions is that they are accompanied by the liberation or absorption of thermal energy. Sometimes so much heat is liberated that it can readily be felt. When the amount of heat evolved is small, special methods of measurement are used.

### **Lightning and Tortoises**

An explosion is a terrible thing. It is terrible because the explosion occurs instantly, in a split second.

But what is an explosion? It is just an ordinary chemical reaction accompanied by the evolution of a large amount of gases. It exemplifies a chemical process which takes place instantaneously, such as the combustion of gun powder in a bullet shell or the explosion of dynamite.

But an explosion is a sort of extreme. Most reactions take some length of time to occur.

There are many reactions which proceed so slowly that they can hardly be detected.

... Imagine a mixture of two gases, hydrogen and oxygen, the components of water, in a glass container. They may stand in it for a very long time: a month, a year, a hundred years, without

a single drop of moisture being detected on the surface of the glass. One might think the hydrogen is not combining with the oxygen at all, but actually it is, though very slowly. It would take thousands of years for a hardly perceptible quantity of water to form at the bottom of the container.



Why is this so? Because of the temperature. At room temperature (15-20°C) hydrogen reacts with oxygen only very slowly. But if we heat the container, its walls begin to sweat, and this is a sure sign that a reaction is occurring. At 550°C the container flies apart in tiny fragments, because at this temperature hydrogen reacts with oxygen eruptively.

Why does heat accelerate this chemical process so, making the "tortoise" move like lightning?

In the free state hydrogen and oxygen exist as the molecules  $H_2$  and  $O_2$ . To combine into a water molecule they must collide. The more often such collisions take place the greater the probability that a molecule of water will form. At room temperature and ordinary pressure each hydrogen molecule collides with an oxygen molecule more than ten billion times per second. If each collision resulted in chemical interaction, the reaction would proceed faster than an explosion, in the course of one ten-billionth of a second.

But we do not observe any change in our container: neither today, nor tomorrow, nor in ten years. Under ordinary conditions only very rare collisions result in chemical reaction. The trouble is that the hydrogen and oxygen collide as molecules.

Before they can react they have to break up into atoms. To put it more exactly, the valence bonds between the oxygen atoms and the hydrogen atoms in their molecules must be weakened. They must be weakened to such an extent that they should not be able to prevent the combination of unlike hydrogen and oxygen atoms. Now

the temperature is the whip which makes the reaction go faster. It increases the number of collisions many times over. It makes the molecules vibrate more strongly, and this weakens their valence bonds. And when hydrogen and oxygen meet each other at the atomic level, they react instantly.

### **The Magic Barrier**

Imagine this.

Hardly has hydrogen been mixed with oxygen than water vapour appears. Hardly does an iron plate have come into contact with air than it becomes coated with reddish brown rust, and a few minutes later the solid lustrous metal has turned into a loose powder, iron oxide.

All the chemical reactions in the world proceed at a breath-taking speed. All molecules react with each other independent of the energy they possess. Each collision between two molecules results in their chemical union.

All the metals would disappear from the face of the Earth, because they would be oxidized. Complex organic substances, including those constituting living cells would change into simple, but more stable compounds.

It would be a strange world, a world without life, a world without chemistry, a fantastic world of very stable compounds with no inclination to enter into chemical reactions.

Fortunately no such nightmare threatens us. There is a magic barrier which stands in the way of such a universal "chemical catastrophe."

This barrier is known as activation energy. Molecules cannot enter into chemical reactions

unless their energy equals or exceeds their activation energy.

Even at ordinary temperature there will be molecules, among those, say, of hydrogen and oxygen, with energies greater than or at least equal to their activation energy. That is why water forms, though very slowly, under such conditions. The reaction is slow because the number of sufficiently energetic molecules is too small. But a high temperature brings many molecules up to the activation barrier, and the number of instances of chemical interaction between hydrogen and oxygen grows enormously.

### **Snake with Its Tail in Its Mouth**

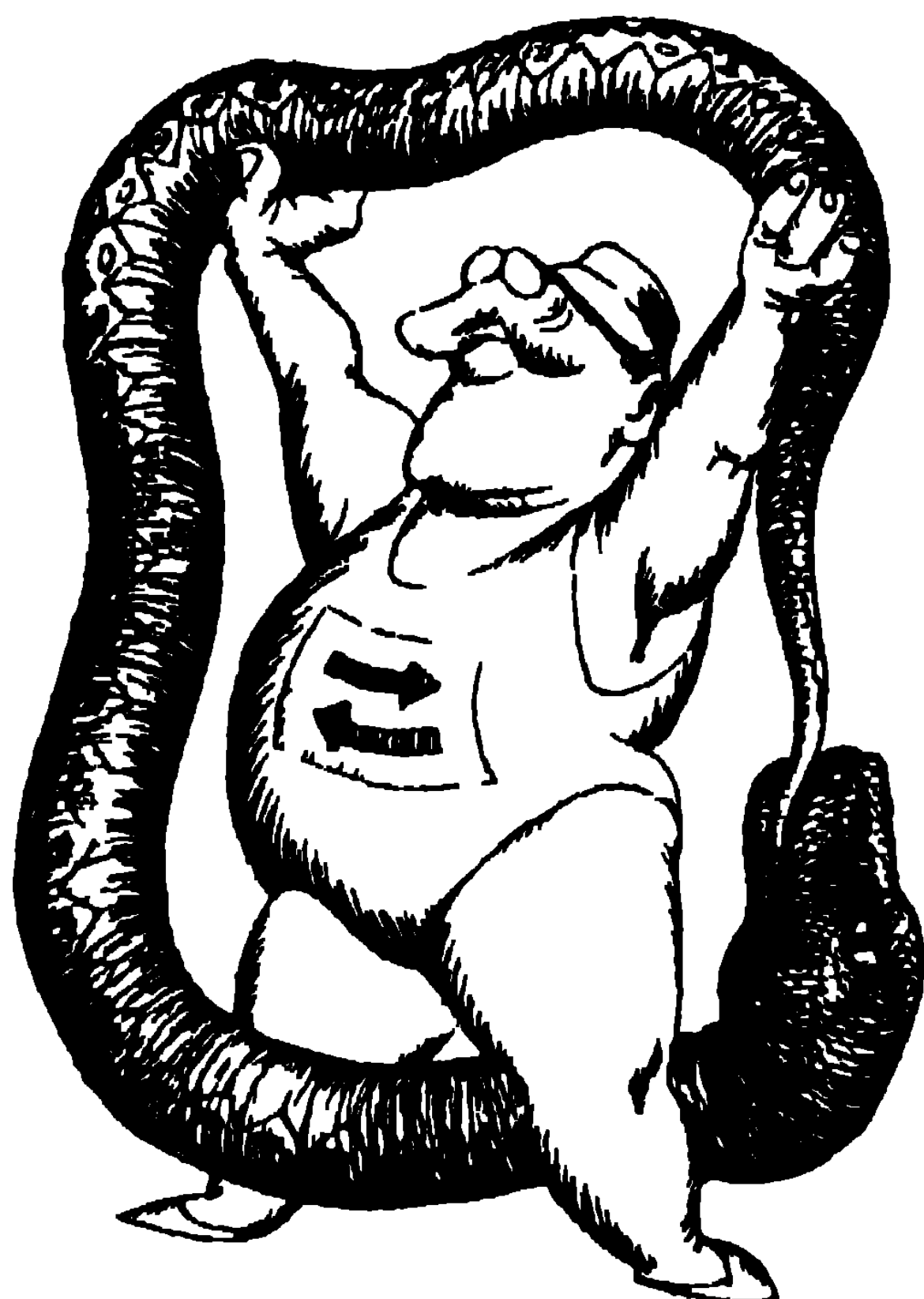
Medicine has its specific symbol which has come down to us from ancient times. Today military doctors of many countries wear badges on their shoulder straps in the form of a snake coiled around a staff or the stem of a cup.

Now there is a similar symbol in chemistry. It is a snake with its tail in its mouth.

The ancients had a cult of all kinds of mystic signs, the meaning of which is often difficult to explain today.

So much for mystic signs, but the "chemical snake" has a quite definite meaning. It symbolizes a reversible chemical reaction.

Two atoms of hydrogen and one of oxygen combine to form a molecule of water. Simultaneously another molecule of water decomposes into its component parts. Two opposite reactions take place in the same instant: the formation of water (the forward reaction) and its decomposi-



tion (the back reaction) A chemist would represent these two contradictory processes as follows  $2\text{H}_2 + \text{O}_2 \rightleftharpoons 2\text{H}_2\text{O}$  The arrow pointing to the right indicates the forward reaction, and that pointing to the left, the back reaction

Fundamentally, all chemical reactions without exception are reversible.

At first the forward reaction predominates The scales tilt towards the formation of water molecules Then the opposite reaction begins to increase Finally, there comes a moment when the number of molecules forming equals the number decomposing, and both reactions, from left to right and from right to left, proceed at an equal rate.

A chemist would say that equilibrium has been established



It is established sooner or later in any chemical reaction, instantaneously in some reactions, or after several hours, days, or weeks, in others.

In its practical activities chemistry pursues two aims. First, it tries to make the chemical process go to completion, so that the initial products react entirely with each other. Secondly, it strives to obtain a maximum yield of the products needed. To accomplish these aims the establishment of chemical equilibrium must be postponed as far as possible. Forward reaction—yes, back reaction—no.

And here the chemist has to become something of a mathematician. He finds the ratio between two quantities, between the concentration of the substances formed and the concentration of the initial substances entering into the reaction.

This ratio is a fraction. The larger the numerator, and the smaller the denominator of any fraction, the larger the fraction.

If the forward reaction predominates, the amount of the products will in time exceed the amount of the initial substances. The numerator will then be greater than the denominator and the result will be an irregular fraction. In the reverse case the fraction will be a regular one.

The chemist calls the value of this fraction the equilibrium constant of the reaction and denote it by  $K$ . If he wants the reaction to result in the largest amount of the product needed he must first calculate  $K$  for different temperatures.

Now here is what this “arithmetic” looks like in practice.

At room temperature  $K$  for the synthesis of ammonia is about 100,000,000. It would seem that



under such conditions a mixture of nitrogen and hydrogen should change instantly into ammonia. But this does not happen. The forward reaction is too slow. Would raising the temperature help?

We heat the mixture to 500°C. . .

But here the chemist would check us:

“What the deuce are you doing? You’ll not get anywhere that way!”

Indeed, he stopped us just in time, this chemist with his calculations. Here is what they show: at a temperature of 500°C  $K$  is only six thousand,  $6 \times 10^3$ ! The “green light” for the back reaction  $2\text{NH}_3 \rightarrow 3\text{H}_2 + \text{N}_2$ . And we would have kept heating the mixture and wondering why we were getting nowhere.

The most favourable conditions for ammonia synthesis are as low a temperature and as high a pressure as possible. This is the domain of another law acting in the realm of chemical reactions.

This law is known as Le Chatelier’s principle, after the French scientist who discovered it.

Imagine a spring built into a fixed support. If it is neither compressed nor stretched it may be said to be in equilibrium. But if it is compressed or stretched the spring comes out of its state of equilibrium. Simultaneously its elastic forces, those that counteract compression or stretching of the spring, begin to increase. Finally, there comes a moment when both forces again balance each other. The spring is once more in a state of equilibrium, but not the same as it was in initially. Its new equilibrium is displaced towards compression or stretching.

The change in the state of equilibrium of a strained spring is an analogy (though rather a

crude one) of the action of Le Chatelier's principle. Here is how it is formulated in chemistry. Let an external force act on a system in equilibrium. Then the equilibrium will shift in the direction indicated by the external influence. It will shift until the reactive forces balance those applied externally.

Reverting to the production of ammonia, the equation of its synthesis shows that four volumes of gases (three volumes of hydrogen and one volume of nitrogen) give two volumes of gaseous ammonia ( $2\text{NH}_3$ ). Increasing the external pressure tends to reduce the volume. In this case the influence is favourable. The "spring is compressed." The reaction proceeds mainly from left to right:  $3\text{H}_2 + \text{N}_2 \rightarrow 2\text{NH}_3$ , and the yield of ammonia increases.

Ammonia synthesis involves a release of heat. If we heat the mixture, the reaction will proceed from right to left, because heating increases the volume of the gases, and the volume of the reactants ( $3\text{H}_2$  and  $\text{N}_2$ ) is larger than the volume of the resultant ( $2\text{NH}_3$ ). Hence, the back reaction will predominate over the forward one. The "spring" will stretch.

Both influences result in a new state of equilibrium, but in the first case it corresponds to an increase in the ammonia yield, whereas in the second case the yield will decrease sharply.

### **How to Make a Tortoise Go Like "Lightning" and Vice Versa**

A hundred odd years ago a chemist carefully introduced a platinum wire into a vessel containing a mixture of hydrogen and oxygen.

The result was extraordinary. The container filled up with fog, that is, with water vapour. The temperature remained unchanged and so did the pressure, but the reaction between hydrogen and oxygen, "calculated" to take thousands of years, occurred in a matter of seconds.

Nor was this all. The platinum wire which had caused the two gases to combine instantly, had undergone absolutely no change. Its appearance, chemical composition, and weight, were exactly the same after the experiment as before it.

Now the scientist was by no means a magician, one of those who invents all kinds of clever tricks to amuse a curious public. This was a serious investigator, the German chemist Döbereiner. The phenomenon he observed is now called catalysis. Substances capable of "making tortoises go like lightning" are called catalysts. Catalysts are literally legion. They may be metals, solid or powdered, oxides of a great variety of elements, salts, or bases. They may be used in the pure form or as mixtures.

Without a catalyst the efficiency of ammonia synthesis is very low, no matter how we vary the pressure and temperature. But the presence of a catalyst makes things entirely different. Ordinary metallic iron with an admixture of aluminium and potassium oxides accelerates the reaction considerably.

Twentieth-century chemistry owes its unprecedented progress to the use of catalysts. Nor is this all. Various vital processes occur in animal and plant organisms owing to the presence of special catalysts called enzymes. The chemistry of all

animate and inanimate nature, such is the range of these wonderful accelerators!

But what if we take a copper, aluminium or iron wire instead of a platinum one? Will the vessel walls again become foggy? Alas! Hydrogen and oxygen display no inclination to react as they did when urged on by the magic platinum wand ..

Not every substance can accelerate any particular process. Therefore chemists say that catalysts are selective in their action: they may influence one reaction vigorously without paying attention at all to another. Of course, there are exceptions to this rule. For example, aluminium oxide is capable of catalyzing several dozen different synthesis reactions of both organic and



inorganic compounds. Finally, different catalysts may make a mixture of the same substances react differently to form different products.

There are substances with no less surprising properties, called promoters. Taken by themselves, they do not influence the course of the reaction, neither accelerating nor decelerating it. But if added to a catalyst, they accelerate the reaction to a much greater degree than the catalyst itself. A platinum wire with "impurities" of iron, aluminium, or silicon dioxide, would cause a still more impressive effect in a mixture of hydrogen and oxygen.

There is also another kind of catalysis, inside-out catalysis. There are anticatalysis and anticatalysts. Scientists called them inhibitors. Their purpose is to slow down rapid chemical reactions.

### **Chain Reactions**

Suppose we have a mixture of two gases, chlorine and hydrogen, in a glass flask. Under ordinary conditions, they react very slowly. But try lighting a strip of magnesium near the flask.

An explosion occurs immediately (if anybody wants to try this experiment, be sure to shield the flask with a hood made of thick wire).

Now why does the mixture of chlorine and hydrogen explode under the action of bright light?

The answer is that a chain reaction is involved. If we heated the flask to about 700 degrees, it would also explode: the chlorine and the hydrogen would combine instantly, in a split second. This would not surprise us, because we know that heat increases the activation energy of the

molecule manifold. But in the experiment just mentioned the temperature did not change. This reaction was caused by light.

Quanta, these tiniest portions of light, carry a large amount of energy. Much more than that needed to activate molecules. Now when a chlorine molecule happens to get into the path of a light quantum, the quantum tears it apart into atoms and passes its energy over to them.

The chlorine atoms are now in an excited, energy-rich state. These atoms, in their turn, bear down upon the hydrogen molecules and tear them apart into atoms too. One of the latter combines with a chlorine atom and the other remains free. But it is excited. It craves to give away part of its energy. To whom? Why, to a chlorine molecule. And when it collides with one, that is the end of the phlegmatic chlorine molecule.

And now again there is an active chlorine ion at large, but it does not take long for this atom to find an outlet for its energy.

Thus we get a long consecutive chain of reactions.

As soon as the reaction starts, more and more molecules are activated by the energy liberated as a result of the reaction. The rate of the reaction increases like an avalanche of snow rolling down a mountain. When the avalanche reaches the valley it dies down. The chain reaction dies out when all the molecules have been caught up by it, when all the hydrogen and chlorine molecules have reacted.

Chemists know multitudes of chain reactions. Our prominent scientist Nikolai Semyonov has studied how these reactions occur in great detail.



Chain reactions are known to physicists too. The fission of uranium nuclei by neutrons is an example of a physical chain reaction

### **How Chemistry Made Friends with Electricity**

It was an odd thing, at first glance, for a respectable man held in high esteem by all his friends, to occupy himself with.

First he prepared little metallic discs. Dozens and dozens of discs, copper and zinc ones. Then he cut up several sponges into round slices and soaked them in salt water. After this he began to stack the pieces on top of each other in much the same way as a child builds a pyramid but, observing a certain sequence: a copper disc, a slice of sponge, a zinc disc. And he repeated this sequence many times. In a word, as long as he could keep the stack from falling down.

The man touched the top of his original structure with a moistened finger, and jerked his hand away immediately: he had received what we would now call a substantial electric shock.

That was how in 1800 the famous Italian physicist Alessandro Volta invented the galvanic cell, a chemical source of current. The electricity appeared in the "volta column" as a result of chemical reactions.

This marked the birth of new branch of science called electrochemistry.

Scientists acquired an instrument by means of which they could produce electric current over a considerable length of time. The current would continue to flow until the chemical process in the "volta column" stopped.



It appeared interesting to find out how electricity would act on different substances.

Two Englishmen, Carlisle a physician, and Nicholson, an engineer, decided to start with water. By that time chemists had sufficient grounds to state that water consisted of hydrogen and oxygen. But somehow they had been unable to obtain conclusive proof.

Carlisle and Nicholson used an electric battery consisting of 17 voltaic cells. It gave a very strong current. And the water began to decompose vigorously into two gases, hydrogen and oxygen; in other words, electrolysis set in. That is what we call the process of decomposition of substances by electricity.

### **Enemy Number One...**

Hundreds and thousands of blast furnaces produce steel and iron all over the world. Economists of different countries scrupulously calculate how many million tons of metal were put out this year and predict the amount to be smelted next year.

And the same economists inform us of the astounding fact that every eighth blast furnace operates in vain. Each year about 12 per cent of the metal produced is ingloriously lost to mankind, falls victim to a merciless enemy. . .

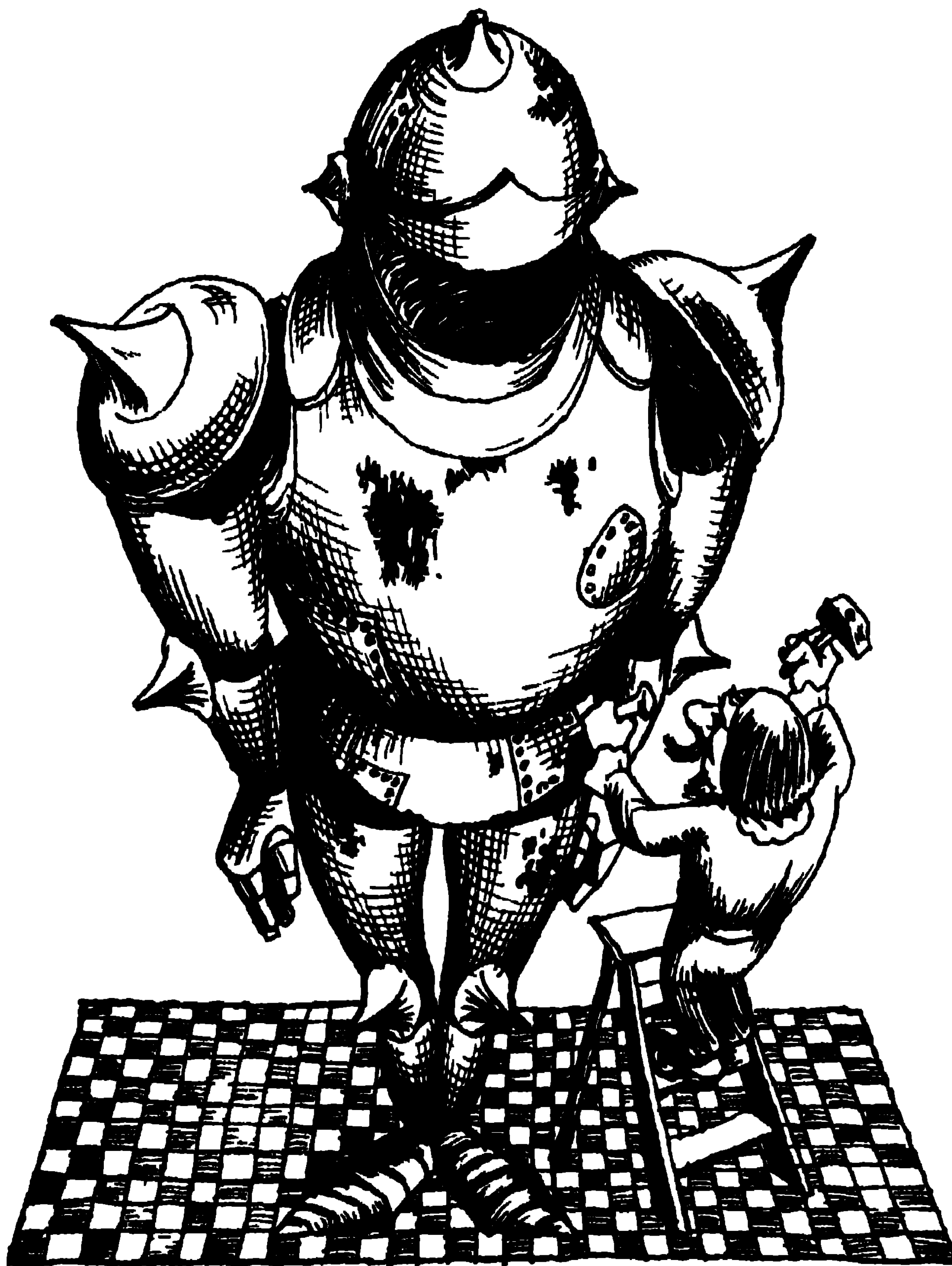
The name of this enemy is simply rust. Science calls it metal corrosion.

Not only iron and steel perish but the nonferrous metals copper, tin and zinc too.

Corrosion means oxidation of metals. Most of them are not very stable in the free state. And even in the air the lustrous surface of a metallic

article becomes coated after some time with ominous varicoloured oxide patterns.

When oxidized, metals and alloys lose their numerous valuable properties. They become weaker and less elastic and their thermal and electrical conductivities decrease.



Once started, corrosion never stops half-way. Slowly but surely the "brown devil" will completely demolish the metallic article. A few oxygen molecules hit the surface of the metal. The first few molecules of oxide are formed. What is called an oxide film appears. It is quite loose and the metal atoms pass through it like through a sieve only to become oxidized immediately in their turn. Also, oxygen molecules pass through the pores of the film into the depths of the metal where they continue their destructive mission.

In a more aggressive chemical environment corrosion proceeds more rapidly. Chlorine, fluorine, sulphur dioxide and hydrogen sulphide are no less dangerous enemies to metals. When a metal corrodes under the action of gases, chemists call the phenomenon gas corrosion.

And what about various solutions? They are also terrible enemies of metals. For example, ordinary sea water. Huge ocean liners must from time to time be docked for general overhaul, to have the corroded platings of their bottoms and sides replaced.

Here is an instructive story about a disastrous blunder an American millionaire once made.

He wanted to have the best yacht in the world. He put in an order and thought up a romantic name "The Call of the Sea." He spared no money. The contractors did their utmost to please their client. It remained only to finish the interior decorations.

But the yacht never went to sea; it never had a chance to. A short time before the day the yacht was to be launched its body and bottom were found to have completely corroded.

Why? Because corrosion is an electrochemical process.

The shipbuilders had decided to plate the bottom of the yacht with a nickel-copper alloy called German silver. It was a good idea because this alloy, though expensive, resists corrosion in sea water very well. It resists corrosion all right, but it is not very strong. And therefore many parts of the ship had to be made of other metals, special steels.

And this was the undoing of the yacht. Powerful galvanic cells formed at the points of contact between the German silver and the steel and the bottom immediately began to disintegrate. The end was sad.

The millionaire's grief was indescribable, and the yacht builders remembered ever after one of the laws of corrosion, that its rate increases sharply if to the principal metal are added other metals capable of forming a galvanic cell with it.

### **...And How to Fight It**

There is a remarkable column in Delhi which has stood there for many centuries. It is remarkable because it is made of pure iron. Time has no effect on it. Ages have passed, but the column still looks quite new. It does not rust. As if corrosion had in this case betrayed its habits...

How the ancient metallurgists succeeded in producing pure iron is quite a puzzle. Some hotheads have contended that it was not even made by man. That visitors from other worlds had put up this obelisk to commemorate their arrival on Earth.

But if we deprive the column of the mysterious aureole of its origin there remains a fact which is very important to chemists, namely, that the purer a metal is, the slower it is attacked by corrosion. If you want to conquer corrosion, use the purest metals possible.

And not only purity is important; it is also necessary to give the surface of the metallic article as high a finish as possible. It appears that separate "hills" and "valleys" can play the part of foreign inclusions. Scientists and engineers have succeeded in obtaining almost ideally smooth surfaces. Articles with such surfaces have already found usage in the construction of rockets and spaceships.

And so is the problem of corrosion prevention solved? By no means. Very pure metals are expensive and difficult to obtain, especially in large quantities. Besides, engineering prefers alloys, because their range of properties is much wider. And an alloy is at least two metals.

Chemists have studied all kinds of corrosion mechanisms in sufficient detail. And when they intend to obtain a new alloy with predetermined properties, they thoroughly consider the "corrosion" aspect among others. There are at present many alloys which resist corrosion very well.

In our everyday life we often have to do with galvanized and tin-plated articles. Iron is coated with a film of zinc or tin to protect it from rust, which helps for some length of time. Besides, we have all seen iron house roofs coated with a dense layer of oil paint.

To weaken or decrease corrosion also means to decrease in some way the velocity of the electro-

chemical reaction constituting the corrosion process. Special organic and inorganic substances called inhibitors are used for this purpose.

At first they were sought by trial-and-error methods and were found by accident.

Even before Peter the Great's time Russian gunsmiths used a curious method. To remove scale from gun barrels they would wash (pickle) them with sulphuric acid mixed with wheat husks. In this primitive manner they kept the acid from dissolving the metal.

The search for new inhibitors is now no longer an inspired art, nor a matter of luck, but an exact science. Hundreds of chemical corrosion inhibitors of all kinds are known today.

We must look after the "health" of metals before they are "infected" by corrosion. This is the main task of the "metal-doctor" chemists.

### **A Luminous Jet**

How many states of matter are there? Modern physicists have counted up no less than seven. Three of them are widely known: gas, liquid, and solid. Strictly speaking, we practically never encounter any others in our daily life. Chemistry has also contented itself with these three for centuries. And only during the last decade has it begun to take an interest in the fourth state of matter, plasma.

Plasma is also a gas, if you like, but not an ordinary one. Besides neutral atoms and molecules it contains ions and electrons. An ordinary gas also contains ionized particles, and the higher its



temperature the more of them it contains. Therefore there is no distinct boundary line between an ionized gas and plasma. But it is conventionally considered that a gas has turned into plasma when it begins to display the principal properties of the latter, say, high electrical conductivity.

Paradoxical as it may seem at first glance, plasma is the master in the universe. The matter of the Sun and the stars, as well as the gases of outer space are in the plasma state. All this is natural plasma. On Earth it has to be prepared artificially, in special apparatuses called plasmotrons. In them various gases (helium, hydrogen, nitrogen, argon) are converted to plasma by means of an electric arc. The luminous plasma jet is compressed by the narrow channel of the plasmotron nozzle and by a magnetic field, so that a temperature of several tens of thousands of degrees develops in it.

Chemists had long dreamt of such temperatures, because the role of high temperatures for many chemical processes can hardly be overestimated. Now this dream has come true: a new branch of chemistry known as plasmochemistry, or the chemistry of "cold" plasma, has been born.

Why "cold" plasma? Because there is also "hot" plasma with a temperature of up to a million degrees. This is the plasma with which physicists are trying to achieve thermonuclear synthesis, i.e., to accomplish the controlled nuclear reaction of transformation of hydrogen into helium.

But chemists are quite content with "cold" plasma. To investigate the course of chemical proces-



ses at a temperature of ten thousand degrees—what could be more alluring?

Sceptics thought this work would be in vain, because in such a hot atmosphere all substances without exception would share the same fate: they would all be destroyed, and even the most complex molecules would be dissociated into separate atoms and ions.

Actuality is far more complex. Plasma not only destroys, but creates too. New chemical compounds can readily be synthesized in it, some of which cannot be obtained by other means.

These are strange substances never described in any chemical textbook:  $\text{Al}_2\text{O}$ ,  $\text{Ba}_2\text{O}_3$ ,  $\text{SO}$ ,  $\text{SiO}$ ,  $\text{CaCl}$ , etc. In them the elements display unusual, anomalous valences. This is all very interesting, but plasmochemistry has set itself more important tasks, namely, the cheap and rapid production of already known valuable substances.

And now a few words about its achievements.

Acetylene is a very important starting material for many organic syntheses, e. g., for the production of plastics, rubbers, dyes, and medicinals. But acetylene is still prepared as of old, by decomposing calcium carbide with water, which is expensive and inconvenient.

In the plasmotron everything is different. Plasma made from hydrogen has a temperature of 5000 degrees. The hydrogen plasma jet carries its enormous energy into a special reactor to which methane is fed. The methane is mixed vigorously with the hydrogen and in the course of one ten-thousandth of a second more than 75 per cent of the methane changes into acetylene.

Isn't that ideal? We should say so! But alas,

there is always a hitch somewhere. If we leave the acetylene for an extra instant in the high-temperature zone of the plasma it begins to decompose. Hence the temperature must be lowered swiftly to a safe level. There are different ways of accomplishing this, but it is the main technical difficulty. So far only 15 per cent of the acetylene formed can be saved from dissociation. But even that is not so bad!

A method of decomposing cheap liquid hydrocarbons plasmochemically to form acetylene, ethylene, and propylene has been developed in the laboratory.

A very important problem that has still to be coped with is the fixation of atmospheric nitrogen. The chemical production of nitrogen-containing compounds, e.g. ammonia, is a very laborious, involved and expensive operation. A few decades ago attempts were made to synthesize nitrogen oxides electrically on an industrial scale, but the economics of the process was too low. Here also plasmochemistry holds much more promise.

### **The Sun as a Chemist**

Once Stephenson, the inventor of the steam locomotive, was taking a walk with his friend Beckland, a geologist, near the first railway in England. Presently they saw a train passing.

"I say, Beckland," asked Stephenson, "what do you think makes that train go?"

"Why, the hand of the driver of one of your wonderful locomotives."

"No."

**"Well then, the steam that moves the machine?"**

**"No."**

**"The fire kindled under the boiler?"**

**"Wrong again; it is actuated by the Sun which shone in that far-off epoch when the plants were alive that afterwards changed into the coal which the driver is shovelling into the stoker."**

**All living things owe their origin to the Sun, especially plants. Try and grow them in the dark, and all you will get is pale thin filaments instead of juicy green stalks. Under the action of solar light chlorophyll (the colouring matter of green leaves) converts the carbon dioxide of the air into complex molecules of organic substances which constitute the bulk of the plant.**

**Hence, the Sun, or rather its rays, are the chief "chemist" synthesizing all the organic substances in plant? It would seem so. Not in vain has the process of assimilation of carbon dioxide by plants been named photosynthesis.**

**It is known that many chemical reactions occur under the action of light. There is even a special branch of chemistry which studies them, called photochemistry.**

**But so far the study of photochemical reactions has not resulted in the creation of either proteins or hydrocarbons in the laboratory. And it is these compounds that are the primary products of photosynthesis in plants.**

**At the initial stage the plant uses only carbon dioxide, water and solar light for the synthesis of very complex organic molecules. But maybe there is something else that plays a part in these processes? Imagine a factory with soda, petró-**

leum, potassium nitrate, etc., being fed through pipes at one end and lorries loaded with bread, sausage, and sugar driving out of its gates at the other end. This is fantasy, of course, but it is just about what happens in plants.

Plants have been found to have their catalysts, called enzymes. Each enzyme makes a reaction proceed only in a definite direction. It appears that the Sun accomplishes photosynthesis not as the sole "chemist," but in collaboration with his colleagues, the enzymes (catalysts). The Sun supplies the energy needed for the reaction and the enzymes make the reaction go in the right direction.

Though we cannot as yet deprive nature, and particularly plants, of their "patents" for the production of many substances, but in some cases we can already make them operate in the direction we need. Of great value to scientists in this respect were their investigations of photosynthesis processes. It has recently been found that if light of different wavelengths is used to illuminate the plants during photosynthesis, chemically different substances are formed. For instance, illumination with red-yellow rays results in carbohydrates as the main compounds whereas blue rays give proteins.

It may therefore be expected that in the near future people will be able, with the aid of plants, to obtain the complex organic compounds they need, on a considerable scale. Indeed, instead of building factories, furnishing them with unique equipment and working out complex synthesis technologies, it will only be necessary to build hothouses and to regulate the intensity and spec-

tral composition of the light rays used. Then the plants themselves will make everything required, from the simplest carbohydrates to the most complex proteins.

## **Two Kinds of Chemical Fetters**

Even in ancient times there were many scientists who did not doubt the existence of atoms. But how are these atoms linked to one another in substances? On this matter philosophical thought was either silent or sailed high and low over the sea of fantasy.

For example, the famous French naturalist Descartes believed that some atoms were furnished with hook-like projections, and others, with eye-like ones. He held that two atoms combined when the hook of one got caught in the eye of the other.

As long as people knew little or nothing about atomic structure, all their ideas about the linkage between atoms, about chemical bonding, remained groundless. The electron helped scientists to discover the truth. But this did not happen all at once. The electron was discovered in 1895, but the first attempts to use it to account for chemical bonding were made only some twenty years later, after the arrangement of electrons around the atomic nucleus became clear.

Not all atomic electrons participate in chemical bonds, but only those situated in their outer or at the most, in their last and second-last shells.

Suppose an atom of sodium meets an atom of

fluorine. The former has one electron revolving on its outside shell, and the latter, seven. The encounter instantly results in a very stable molecule of sodium fluoride. But how? By a rearrangement of electrons.

The sodium atom easily gets rid of its outer electron. In doing so it becomes a positively charged ion and unveils its second-last electron shell. This shell contains eight electrons, an octet configuration which is very difficult to break up.

On the other hand, the fluorine atom readily accepts an additional electron on its outer shell; this makes the latter also an eight-electron shell. And a negatively charged fluorine ion appears.

Positive attracts negative. Electrical forces draw the oppositely charged sodium and fluorine ions strongly together. A chemical bond appears between them. This bond is called ionic, and it is one of the principal types of chemical bonds.

The second is as follows.

How can such a compound as, say, the fluorine molecule  $F_2$  exist? Fluorine atoms cannot discard electrons from their outer shells. Differently charged ions cannot form in this case.

The chemical linkage between the fluorine atoms is accomplished by means of a pair of electrons. Each of the atoms deals out one electron to be pooled for common use. As a result, both of the atoms now have eight electrons, as it were, in their outer shells, six of their own and two pooled ones. Such a bond is called covalent.

The majority of chemical compounds known to us are formed by means of chemical bonds of the first or second type.



## **Chemistry and Radiation**

So far chemists have not invented green leaves But light is already used in practice for accomplishing photochemical reactions. Incidentally, photographic processes are an example of photochemistry in action. Light is the chief photographer.

But the interests of chemists are not confined to light rays. There are also X-rays and radioactive radiations. They carry immense amounts of energy. For instance, X-rays are thousands, and gamma-rays, millions of times more "intensive" than light rays.

Now would chemists be likely to disregard them?

And so there appeared in encyclopaedias and textbooks, in special books and publications, in popular booklets and essays a new term "radiation chemistry". Such is the name of the branch of science which studies the action of radiations on chemical reactions.

Though it is a young branch of science, it can already boast of more than a few achievements.

For instance, one of the most common processes in petroleum chemistry is cracking. As a result of this process the complex organic compounds contained in petroleum split down into simpler ones. Some of the hydrocarbons they form are those contained in gasoline.

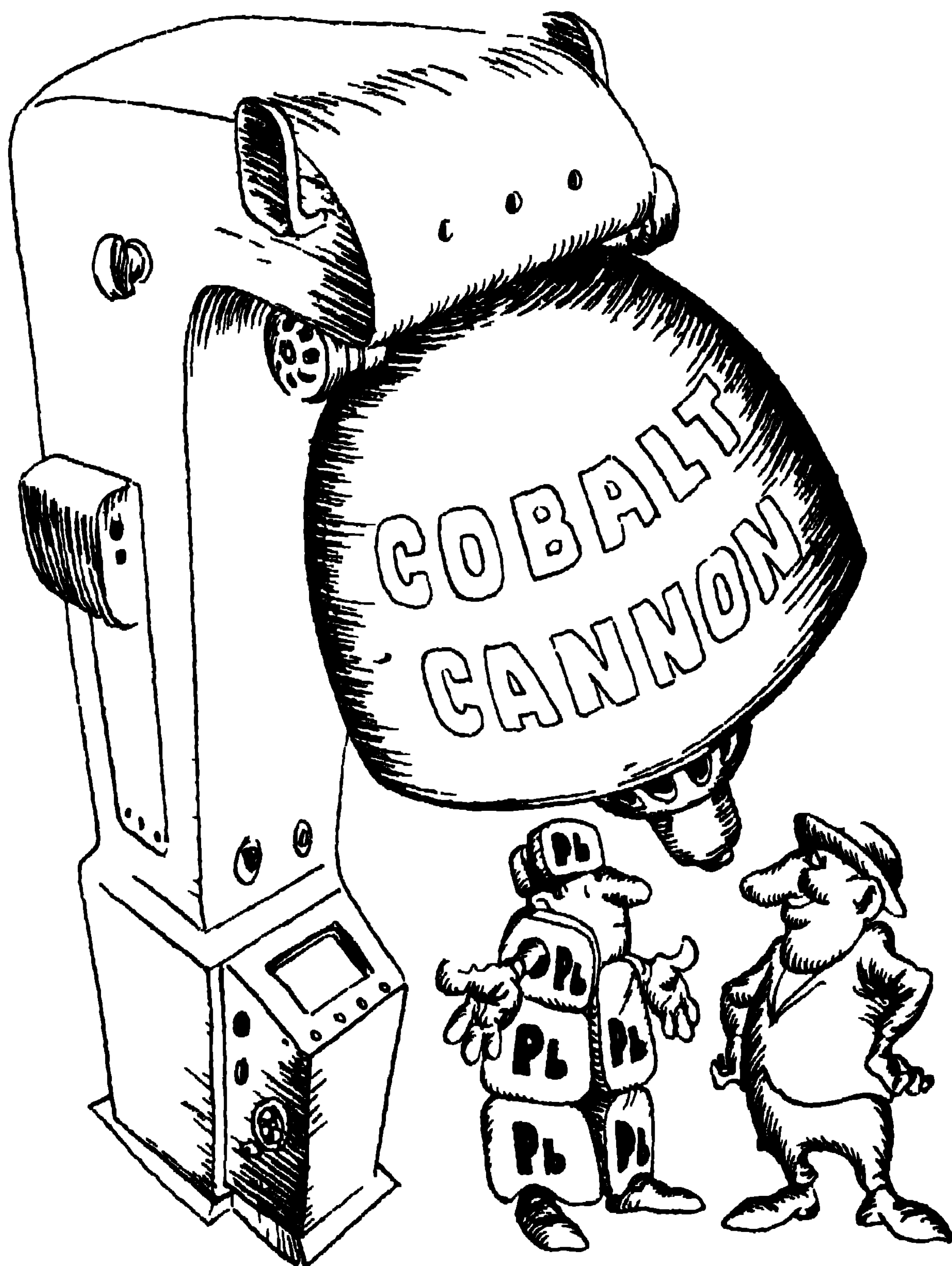
Cracking is a delicate process. It requires high temperatures, the presence of catalysts, and rather a long time.

All this refers to the old way. In the new



way cracking needs neither heat nor chemical accelerators, and takes much less time.

The new way involves the use of gamma-rays. They carry out radiation cracking. They break down the complex organic molecules. Here radiation is a destroyer.



X-rays expose photographic plates and films instantly. They break down the light-sensitive layers of the silver bromide emulsion.

Now here is what some Italian chemists did about four years ago. They moistened the surface of a photographic plate with a solution of the inorganic compounds—titanium sulphate and selenious acid. The plate became insensitive not only to visible light, but to X-rays as well.

What was the reason? Had some chemical reaction occurred between these substances and the silver bromide, resulting in new compounds which resisted irradiation?

By no means! No chemical reaction had occurred, and the sensitivity of the plate was fully restored by washing it thoroughly with water. In a word, nobody knows yet exactly what happened. It is only a hint at an entirely unexpected possibility of radiation protection.

And we already conjure up a picture in our mind's eye of a man dressed in an ordinary suit impregnated with a special chemical compound, a compound capable of stopping death rays.

### **The Longest Reaction**

Hundreds and thousands of the most complex organic compounds have been made by chemists in their laboratories during recent years. Some of them are so complex that it is no easy thing even to write their structural formulas on paper. It requires quite a lot of time in any case.

The greatest victory scored by organic chemists is unquestionably the synthesis of a protein mo-

lecule, of the molecule of one of the most important proteins.

We are referring to the chemical synthesis of insulin, the hormone which controls carbohydrate metabolism in the organism.

If we tried to tell you about the constitution of the insulin molecule, it would take us several pages. Remember that some of the details of structure of this protein molecule are still not very clear even to specialists in chemistry. Insulin is a real giant molecule, though the number of elements contained in it is rather limited. But they are arranged in very elaborate combinations.

And so, for the sake of simplicity, let us assume that the insulin molecule consists of two parts, or rather two chains—chain *A* and chain *B*. These chains are bound to one another by means of what is called a disulphide bond. In other words, they are bridged, as it were, by a crosslink consisting of two sulphur atoms.

The plan for the general attack on insulin was as follows. First, chains *A* and *B* were to be synthesized separately. Then they were to be connected with a disulphide crosslink between them.

Now for some arithmetic. To produce chain *A* the chemists had to perform almost a hundred different consecutive reactions. Chain *B* required more than a hundred. And so all this took many months of very painstaking work.

But finally both chains were obtained. Now they had to be connected. And this is where the main difficulties sprang up. Disappointment followed upon disappointment. Nevertheless, one fine evening there appeared in the laboratory log the

laconic statement: "The synthesis of the insulin molecule is fully accomplished."

Scientists had to go through two hundred and twenty three consecutive stages to obtain insulin artificially. Just think of that figure: hitherto not a single known chemical compound had been so difficult to prepare. It had taken ten men almost three years of incessant work to do it...

But biochemists report a very curious thing: in a living cell the synthesis of protein takes ... from two to three seconds.

Three years, or three seconds! How far more perfect is the synthesis apparatus of the living cell than that of today's chemistry!



# **A Chemical Museum**





## **A Question with No Answer**

If we gathered together the greatest chemists of the world and asked them only one question: how many chemical compounds can the elements of the Periodic System form, this authoritative assembly would be unable to give even an approximate answer.

We know the simplest chemical compound: it is the hydrogen molecule. There can be no simpler compound, because hydrogen is the first and lightest representative of the Mendeleev Table.

But what about the most complex? Here we can say nothing definite. Chemistry knows truly gigantic molecules consisting of tens and hundreds of thousands and even millions of atoms. Yet nobody can say whether there is any limit to complexity.

On the other hand, we could estimate comparatively precisely how many chemical compounds are known. But the number we got today would be out of date by tomorrow. At present about ten new substances are synthesized each day in the laboratories of the globe, and this daily yield increases from year to year.

The chemical information service tells us that altogether about two million chemical compounds have been isolated from natural raw materials or obtained artificially.

This number is impressive but it appears that the contributions of the inhabitants of the Big House vary widely.

The number of compounds of, say, the noble gases, helium, neon, and argon, is zero. Authentically three compounds have been obtained for

the rare-earth element promethium (physicists prepare it artificially in nuclear reactors), and these are very ordinary ones: the hydrate, the nitrate, and the chloride. As to the other artificial elements, the situation is no better. Some of them have been prepared in amounts of so many atoms... So what is there to be said about their compounds!

But there is a unique element in the Mendeleev Table. It is quite exceptional with respect to the number of complex substances it can form.

It is the occupant of Flat No. 6 in the Big House and its name is carbon.

Of the two million different molecules in existence, one million 700 thousand are molecules with a framework of carbon atoms. These compounds are studied by a huge branch of chemistry called organic chemistry. The compounds of all the other elements constitute the domain of inorganic chemistry.

So you see, organic substances are almost six times more numerous than inorganic substances.

A new organic substance is much easier to synthesize, as a rule. It would be excellent if inorganic chemists could report the preparation of at least one new compound per day. True, prospects have become more promising in recent years

Organic chemists are aided by a remarkable peculiarity of carbon atoms.

### **The Reason for and the Consequences of Diversity**

Carbon atoms form chains very readily, arranging themselves one after the other in long lines.

The shortest chain has two carbon atoms. For example, the molecule of the hydrocarbon ethane has two links in its chain:  $\text{H}_3\text{C}-\text{CH}_3$ . Well, and what about the longest? This is unknown so far. Compounds with 70 carbon links in their chain have been obtained (It should be noted that ordinary compounds are meant here, and not poly-



mers. In the latter case the hydrocarbon chains may be much longer.)

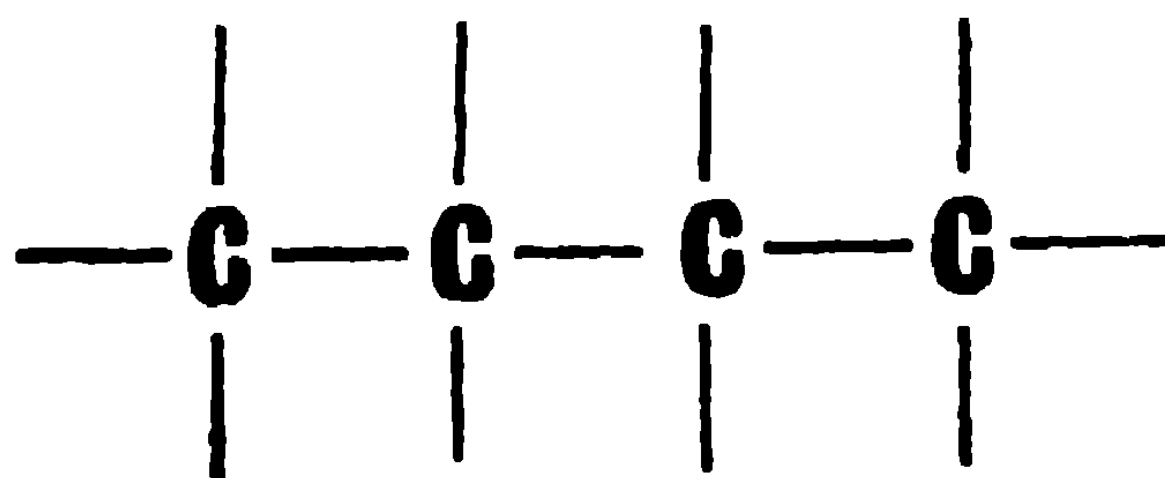
None of the other elements can do anything of the kind. Only silicon allows itself the luxury of forming a six-link chain. And scientists have obtained a curious compound of germanium, the hydrogen germanide  $\text{Ge}_3\text{H}_8$ , in which three metallic atoms are linked into a chain. This is the only case of its kind among the metals.

To put it briefly, carbon has no rival in "chain-formation capacity."

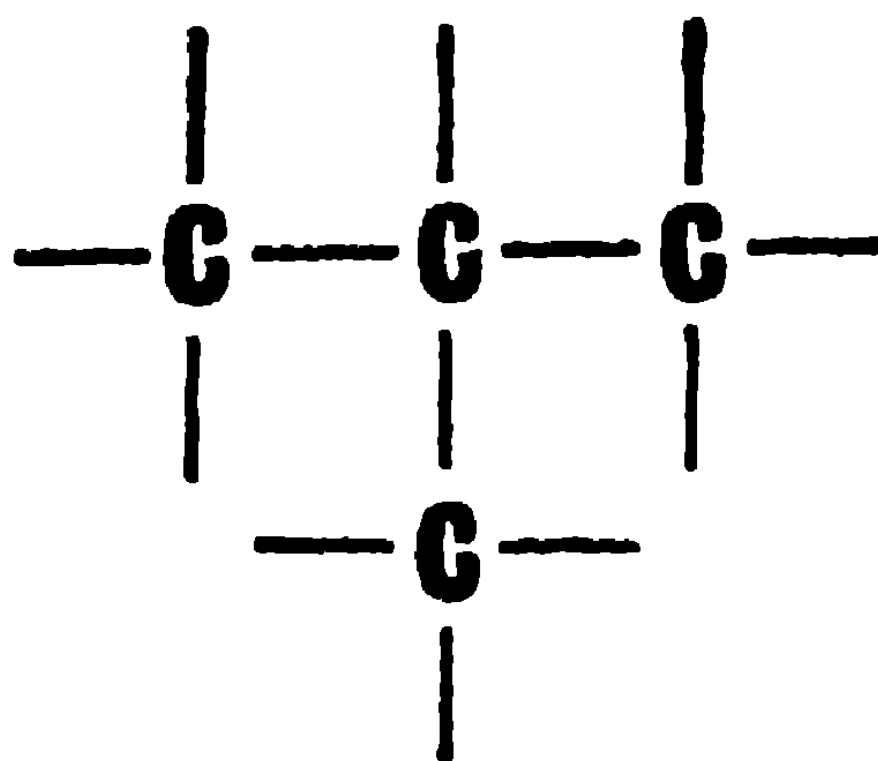
But if carbon chains were only linear, organic chemistry would never know such a fabulous number of compounds.

Chains are capable of branching and of closing up into cycles. These are polygons, consisting of three, four, five, six, and more carbon atoms.

The chain of the hydrocarbon butane consists of four carbon atoms.



Here the atoms are "lined up". But they may take up the following positions:



The number of atoms is the same, but their arrangement is different. And the second formula represents a different substance with other properties and a different name, isobutane.

Five carbon atoms can form five branched chains besides the linear one. And each of these structures represents a separate chemical substance.

Chemists have thought up a special name for varieties of chemical compounds which contain the same atoms arranged differently: they are called isomers. The more carbon atoms in the molecule, the larger the number of isomers. As a matter of fact, their number grows almost in geometrical progression.

And this adds hundreds of thousands of new compounds to the reserves of organic chemistry

## **Chemical Rings**

No few legends are told about how great scientists made their great discoveries.

It is said that Newton was once absorbed in thought in his garden, when suddenly an apple fell to his feet. This gave him the clue to the law of gravity.

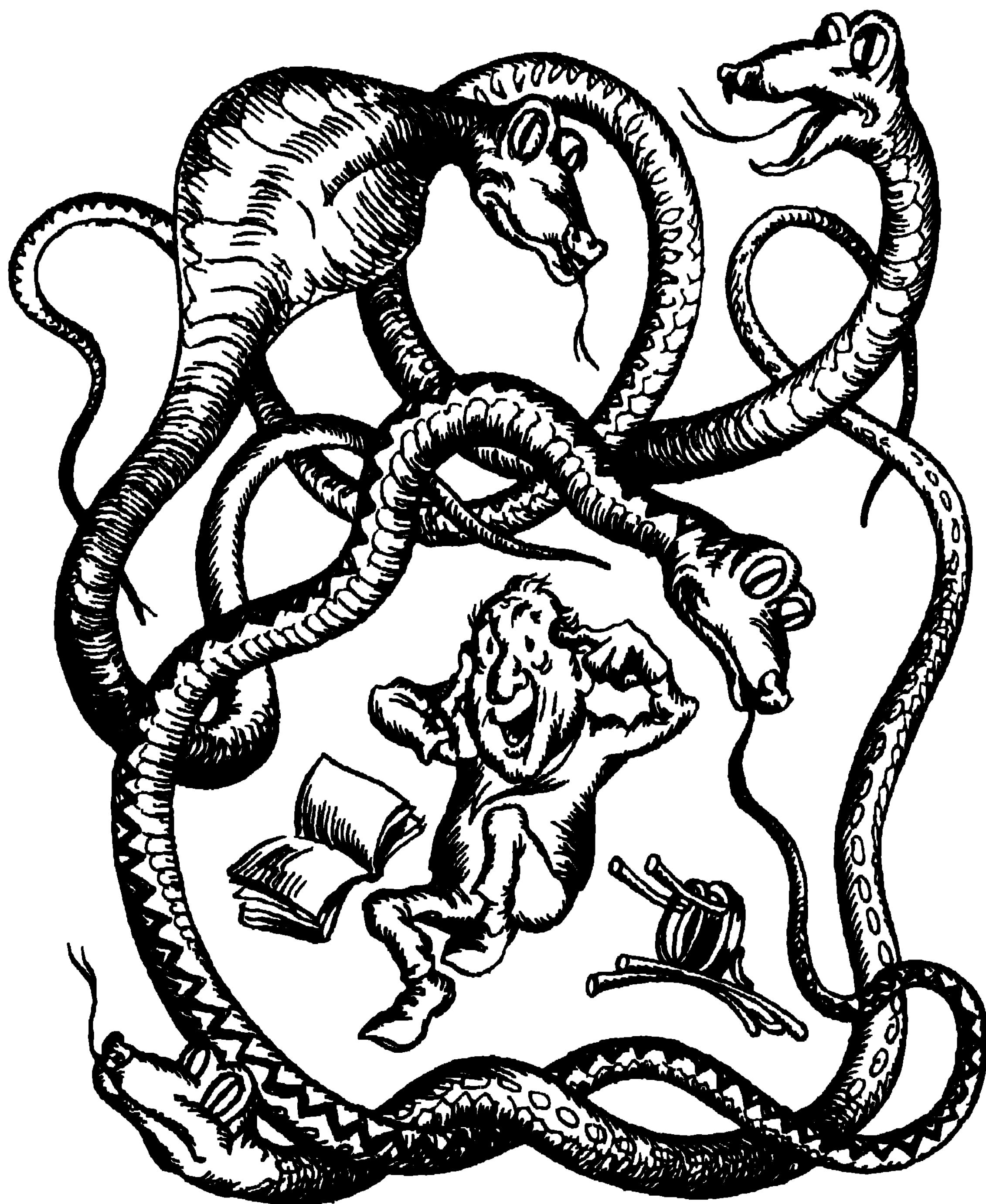
It has been said that Mendeleev first saw the Periodic System in his dreams. All he had to do was to wake up and put his "dream" down on paper.

In a word, all kinds of stories have been thought up about discoveries and discoverers.

But the idea that occurred to the famous German chemist Kekulé was really suggested by a rather curious picture.

Scientists had long known about benzene, one of the most important organic compounds. They knew that it consisted of six atoms of carbon and six atoms of hydrogen. They had studied many of its reactions.

But they did not know the main thing, namely, how the six carbon atoms were arranged in space.





This problem gave Kekulé no peace. And here is how he solved it. Let him speak for himself: "I was at my desk writing a textbook, and was getting nowhere. My thoughts were far away. Atoms danced before my eyes. My mind's eye could distinguish long rows of them writhing hither and thither like snakes. But lo! One of the snakes suddenly caught hold of its own tail and began rotating before my eyes as if teasing me. I started as if awakened by a stroke of lightning."

The casual image conjured up in Kekulé's mind suggested that carbon chains could close up into cycles.

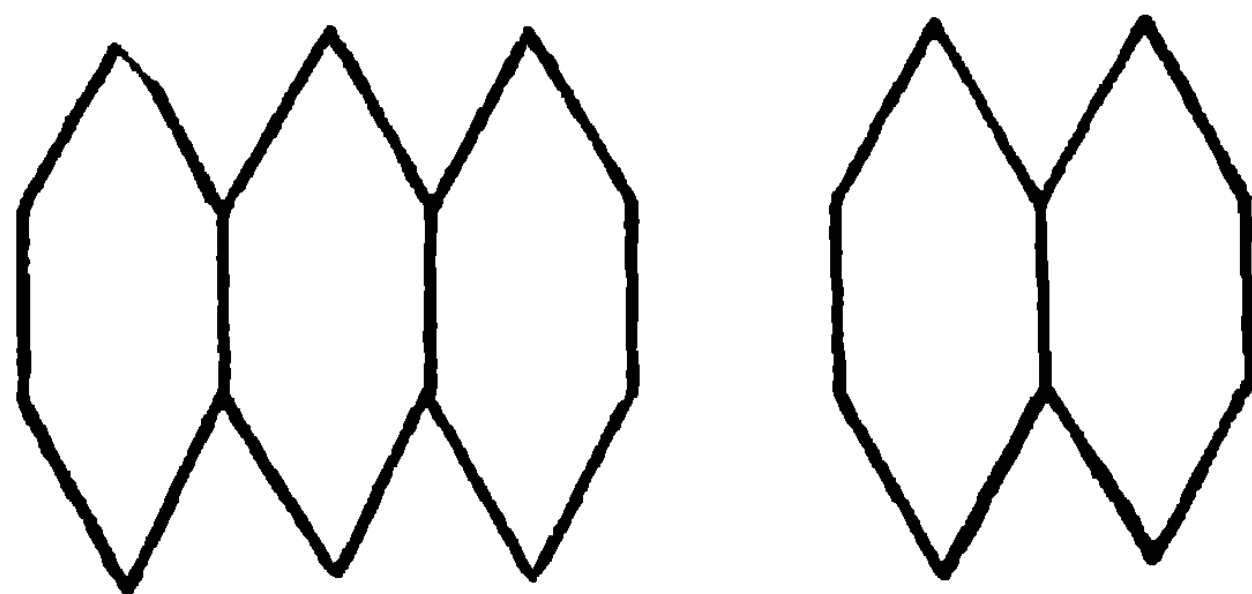
After Kekulé chemists began to represent the structure of benzene like this:

The benzene ring has played a tremendous role in organic chemistry.

Rings can contain different numbers of carbon atoms. Rings may also grow together, forming weird geometrical figures. The world of rings has just as wide a range of structures as open carbon atom chains. Any book on organic chemistry bears some resemblance to a textbook of geometry, because "geometrical figures"—the structural formulas of complex organic compounds—are found on almost every page.



Here are two of the amusing patterns benzene rings can form



The pattern on the left is the structural formula of naphthalene. The one on the right is anthracene, a constituent of hard coal.

### **A Third Possibility**

It was thought that the element carbon was a union of three substances. Scientists call this "triple" allotropy. In other words, one and the same element can exist in three allotropic modifications.

The three carbon substances were diamond, graphite, and carbon black. They differ greatly from one another: the 'king of hardness', diamond, soft scaly graphite, and dull carbon black. The difference between them is due to dissimilar arrangement of the carbon atoms in their molecules.

In diamond they occupy the peaks of a geometrical figure called a tetrahedron and are bound very strongly. That is what makes diamond so hard.

In graphite, on the contrary, the carbon atoms are arranged in planes and the bonds between the

planes are weak. That is why graphite is so soft and scales off so easily.

As to the structure of carbon black there has been much controversy. For a long time the dominating opinion was that carbon black is not a crystalline substance. It was regarded as an amorphous variety of carbon.

But comparatively recently it was found that graphite and carbon black are practically the same and have the same molecular arrangement.

And so there remained only diamond and graphite and no third.

But scientists decided to make a third variety of carbon artificially. The task was formulated as follows.

In diamond and graphite the chains of carbon atoms are closed, though arranged differently in space. Now could the carbon atoms be made stretch out in a long linear chain? In other words, is it possible to produce a polymeric molecule consisting only of carbons arranged in a straight line?

The first thing required to prepare any chemical product is the starting material. The only raw material that could serve for the preparation of "carbon No. 3" is acetylene, a compound of two carbon atoms and two hydrogen atoms,  $C_2H_2$ .

Why acetylene? Because in its molecule the carbon atoms are tied up with the least possible number of hydrogen atoms. Extra hydrogens would be an obstacle to the synthesis.

Acetylene has another important feature: it is very reactive, as the chemists say. The carbon atoms in its molecule are held together by three chemical bonds ( $H-C\equiv C-H$ ), and two of them



are comparatively easy to break, and can be used subsequently to connect the carbons with the atoms of other molecules, for instance, with molecules of the same acetylene

Thus the first step in the planned operation was to prepare the polymer polyacetylene from monomeric acetylene

This was not the first attempt. In the 19th century the German chemist Baeyer tried to accomplish this reaction. But the best he could produce was tetraacetylene, a combination of four acetylene molecules. But even so this compound proved very unstable. The same path was tried by other chemists in various countries. But all their efforts ended in disappointment.

Only the powerful present-day methods of or-

ganic synthesis have finally made it possible to produce polyacetylene. Soviet scientists produced a new class of organic compounds known as polyynes. These new-born substances immediately found practical usage, because they turned out to be excellent semiconductors.

Now the second step had to be made towards synthesis of the third variety of carbon. This was to exclude the hydrogen atoms from the polyacetylene molecules, and to exclude them in such a manner as to preserve a chain consisting only of carbon atoms.

In the language of chemistry the process by means of which the hydrogen atoms were to be excluded bears the long and tedious name of oxidative dehydropolycondensation. There is no point in trying to explain the essentials of this process, in laboratory logs the description of the process took up scores of pages, because the removal of hydrogen from polyacetylene proved no easy task.

Nevertheless, Soviet scientists scored a brilliant success.

...An unattractive black powder resembling soot. Chemical analysis showed 99 per cent pure carbon. But ninety-nine is not one hundred.

Strictly speaking, one more step remains to complete victory. The notorious last per cent of hydrogen has to be got rid of. It is this per cent that prevents the carbon atoms from falling into straight-line formation, from arranging themselves in parallel chains. It is the last obstacle in the way to "carbon No. 3."

Chemists call this synthesized "almost third" variety of carbon carbyne. It has already de-

monstrated some remarkable qualities. It is an excellent semiconductor, possesses photoelectric properties and its heat resistance is breathtaking: fifteen hundred degrees means nothing to it.

We are confident that "one hundred per cent" carbyne will become a reality in the very near future.

### **A Few Words About Complex Compounds**

There were many great chemists in the nineteenth century. But three of them were peerless. They accomplished more for their science than anyone else. They laid the foundations of modern chemistry.

Two of them were Dmitry Mendeleev, the creator of the Periodic Law and the Periodic System of Elements, and Alexander Butlerov, the author of the theory of structure of organic compounds.

The third was the German chemist Alfred Werner. His discovery is covered by the two words "coordination theory," but it was epoch-making for inorganic chemistry.

...It all started when chemists took up the study of reactions between metals and ammonia. To a solution of an ordinary salt, such as copper chloride, they added spirits of ammonia. Evaporation of the solution resulted in beautiful blue-green crystals. Analysis showed these crystals to be of a simple composition, but it was a puzzling simplicity.

The formula of copper chloride is  $\text{CuCl}_2$ . The copper is divalent, and everything is quite clear.

Nor were the crystals of the "ammonia" compound too complex:  $\text{Cu}(\text{NH}_3)_2\text{Cl}_2$ .

But what forces combine the two ammonia molecules so stably with the copper atom? Both valences of this atom are already used up in the bond with the chlorine atoms. It appears that copper must be tetravalent in this compound.

Another example is the analogous cobalt compound  $\text{Co}(\text{NH}_3)_6\text{Cl}_3$ . Cobalt is a typical trivalent element, but in this compound it seems to exhibit nonavalence!

Multitudes of such compounds were synthesized, and each of them was like a delayed-action mine nested in the foundation of the theory of valence.

The situation defied logical explanation. Many metals displayed quite preposterous valences.

Alfred Werner succeeded in accounting for this strange phenomenon.

His idea was that after saturating their ordinary, legitimate valences, atoms can still display additional valence. For instance, after copper has spent its two main valences on chlorine atoms, it can find two additional ones to combine with ammonia.

Compounds such as  $\text{Cu}(\text{NH}_3)_2\text{Cl}_2$  are called complex. In this compound the cation  $[\text{Cu}(\text{NH}_3)_2]^{2+}$  is complex. There are many substances in which the anion is of complex structure; for example,  $\text{K}_2[\text{PtCl}_6]$  contains the complex anion  $[\text{PtCl}_6]^{2-}$ .

But how many secondary valences can a metal display? This depends on its coordination number. The smallest value of the latter is 2, and the largest 12. In the copper-ammonia compound men-

tioned above it is 2, showing how many molecules of ammonia are combined with the copper atom.

Thus was solved the riddle of unusual valences.

A new branch of inorganic chemistry sprang up, the chemistry of complex compounds

Over a hundred thousand complex compounds are known at present. They are studied in chemical institutions and laboratories all over the world. They are of interest not only to theoretical chemists who try to find how all things are built and why they are built so.

Without complex compounds there would be no life. Both haemoglobin, an important component of the blood, and chlorophyll, the basis of all plant life, are complex compounds. Many ferments and enzymes are of complex constitution.

Analysts use complex compounds for carrying out very complicated analyses of a wide range of substances.

Many metals can be obtained in a very pure state with the aid of complexes. They find application as valuable dyes, and for softening water. In a word, complex compounds are omnipresent.

### **A Surprise In a Simple Compound**

In our days it is more than easy to learn to make photographs. Even a schoolchild can make them. He may not know all the secrets of the process (between ourselves, some of them are not known even to specialists), but to take snapshots and to develop them all he needs is a little practice and some good advice from adults.

And so there is no need to go into the details of what a photographer does.



He knows well, for instance, that sometimes brown spots appear on photographs, especially if they are kept in the light for a long time. The photographer could explain that they are due to underfixing of the paper (or plate).

In scientific terms, this means that the plate or paper had not been held long enough in the fixing solution.

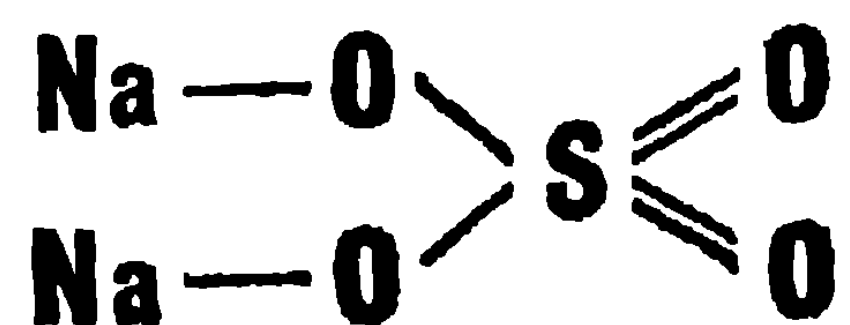
What is the fixer needed for? Anyone who has ever taken the least interest in photography can answer that.

It is needed to remove the silver bromide left undecomposed on film surfaces after exposure.

Many different fixers have been invented. But the cheapest and most popular of them is hypo. Chemists call it sodium thiosulphate.

But first a few words about sodium sulphate. It was discovered by the German chemist Johann Glauber and has been known for a very long time. That is why another name for sodium sulphate is Glauber's salt. Its formula is  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ .

Chemists are fond of drawing the structural formulas of compounds. They draw anhydrous sodium sulphate like this:



A glance at this formula makes it clear even to a greenhorn in chemistry that the sulphur in it is positively hexavalent, and the oxygen, negatively divalent.

The constitution of the thiosulphate is almost the same. Except for a trifle, namely, that one of the oxygen atoms is replaced by a sulphur atom:

*or*



Simple, isn't it? But what a curious compound thiosulphate is! It contains two sulphur atoms of different valences. One of them has the charge 6+, and the other 2—. It is not so very often that chemists come across such phenomena

We not infrequently find the unusual in the most ordinary things.

### What Humphry Davy Did Not Know

The list of scientific works of the famous English chemist Humphry Davy is very long indeed.

He was not only a talented scientist, but an ingenious investigator as well. Whatever problem Davy undertook he almost always solved it successfully. He prepared not a few new chemical compounds and developed several new methods of investigation. Finally, Davy discovered four elements, namely: potassium and sodium, magnesium and barium.

One of his works is a short paper reporting the preparation of a simple chemical compound, chlorine hydrate, in which six molecules of water are combined with the chlorine molecule:  $\text{Cl}_2 \cdot 6\text{H}_2\text{O}$ .

Though Davy studied the properties of this substance very thoroughly, he never knew that he had obtained a compound of an entirely new type, a compound without chemical bonds.

This became clear only to chemists of the twentieth century. They attempted to account for the existence of chlorine hydrate according to the modern conception of valence. But they failed: the substance was too hard a nut to crack, nor was it the only one.

For decades chemists sought the answer to the question whether the inert gases were really so hopelessly inert, or whether they could somehow be made to enter into chemical reactions. We already know the answer to this question. But while it was still a question scientists succeeded in preparing several hydrates of argon, krypton, xenon, and radon.

These hydrates contained no ordinary chemical bonds. Yet many of them are comparatively stable substances.

The simple organic compound urea was another riddle to chemists. It combined readily with many hydrocarbons and alcohols. This strange "friendship" evoked surprise: what forces could cause urea and alcohol to attract each other? Anything but chemical forces. . .

Be that as it may, but the new class of compounds, substances not containing chemical bonds, grew at a terrific rate.

However, there turned out to be nothing supernatural about it.

The two combining molecules are not equal. One of them acts as the "host", and the other as the "guest."

Host-molecules form a crystal lattice. There are always interstices in this lattice not filled with atoms. The "visiting" molecules enter these interstices. But the hospitality is of a rather strange kind. The strangers stay with their host for a very long time, because it is not easy for them to leave the interstices of the crystal lattice.

In this way, molecules of the gases chlorine, argon, krypton and others get trapped, as it were, in the interstices of the crystal lattice of water

Now chemists call these and a number of other substances not having chemical bonds between different molecules clathrate (or cellular) compounds.

## **26, 28, or Something Quite Remarkable**

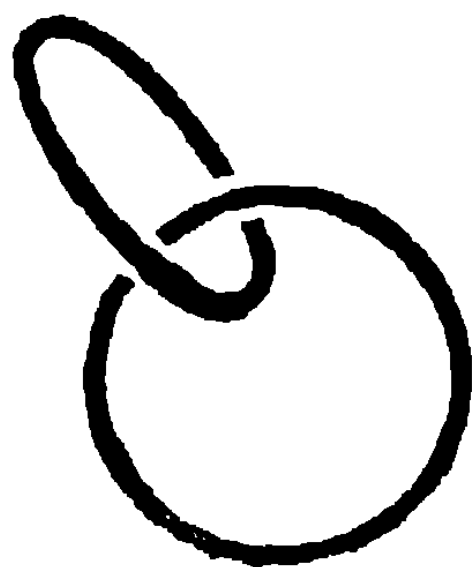
These substances are called catenanes, from the Latin "catena" meaning a chain.

So what of it? The word chain doesn't tell us much. It is no less common in the organic chemist's vocabulary than any other term.

But there are chains and chains. We have had occasion to see that they may be linear or branched and sometimes form rather intricate patterns.

But now stop and think a moment: in organic compounds the notion chain is a graphic, but not very strict conception. According to its everyday meaning, the word chain signifies something different. Its links have no rigid mechanical bond but pass freely through one another. In complex organic compounds the cycles are "soldered", so to say, to one another, as, for instance, the three benzene rings in anthracene. It resembles a chain of cycles, but still it is not quite a chain.

And so chemists began to puzzle over the question whether separate cycles could be connected like the links in an ordinary chain, like this:



In short, what they wanted was to connect cyclic molecules without a chemical bond, in a purely mechanical fashion, so to say.

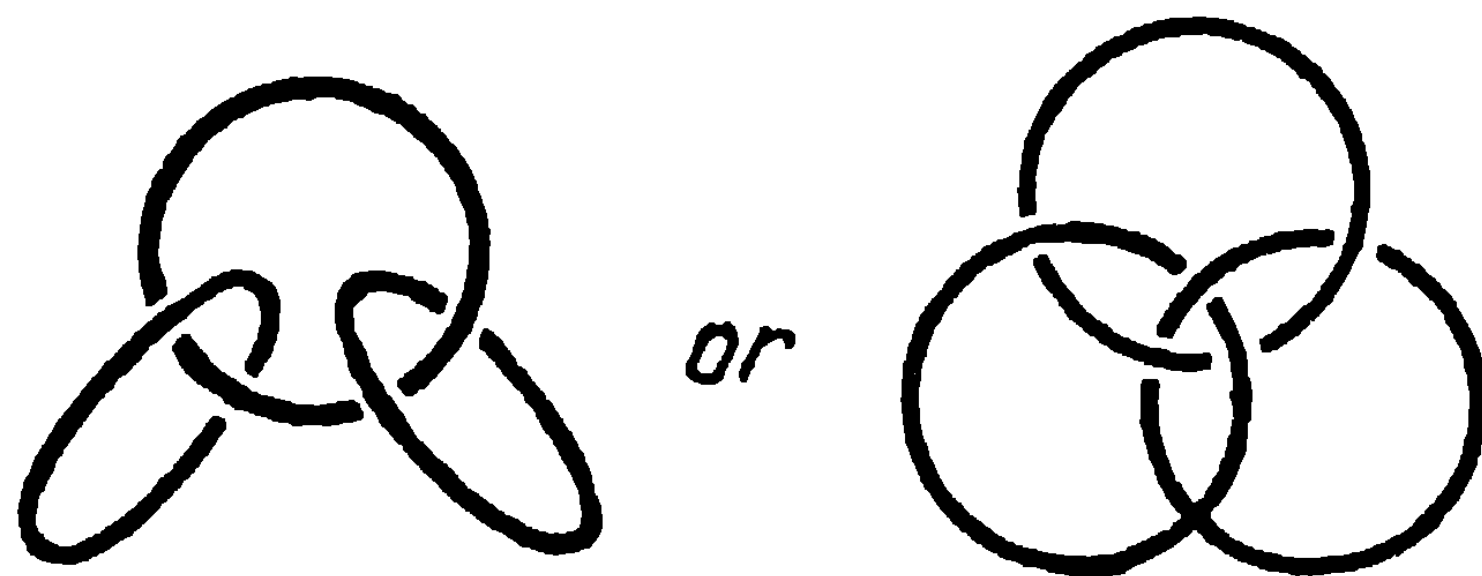
This attractive idea matured for many years in the minds of scientists. Theory was on their side. It set no unsurmountable obstacles to such a synthesis. Chemists were even able to calculate theoretically the number of carbon atoms the cycles would have to consist of to be interlaceable.

As regards practice, however, the situation for a long time was anything but bright. The synthesis would go into a deadlock at some stage each time. And the chemists had to keep thinking up all kinds of new tricks.

The new compound was born on a fine April morning in 1964. It was brought to life by two German chemists, Luttringhaus and Schill. This required twenty consecutive chemical operations, twenty stages.

The compound consists of two cyclic molecules interlaced like the links of a chain. One of the links contains 26, and the other, 28 carbon atoms. Hence the prosaic name of the substance: catenane 26, 28.

Two interlaced rings is now already the past of catenane chemistry. Now scientists are working on more intricate ring combinations, such as:



These are models of three-linked catenanes. In the one at the left the middle link must contain 26 carbon atoms, and the outer ones, 20 each. To give a complex interlacing of three rings (the catenane on the right) they must consist of at least 30 atoms each.

The external appearance of the first-born in the new family, catenane 26, 28, is surprisingly commonplace: it is a white crystalline powder melting at 125°C.

Do catenanes occur in nature? In nature everything is expedient; it exerts no abilities in vain. If natural catenanes do exist, there must be some specific function they fulfill.

It is up to the scientists to find this out.

### **A Eulogy to Cadet's Liquid**

In 1760 the little known French chemist Cadet made history without suspecting it.

In his laboratory he performed the following chemical experiment (we have no idea what for).

Cadet heated potassium acetate with arsenic oxide. What the result was he never found out,

because the substance that formed was of a truly diabolical disposition.

It was a black, thick liquid. It fumed in the air, and burst into flame readily. Besides, it had an utterly unbearable odour.

Cadet's "concoction" was analysed about seventy years later. Its main components were found to be arsenious compounds of a very singular nature

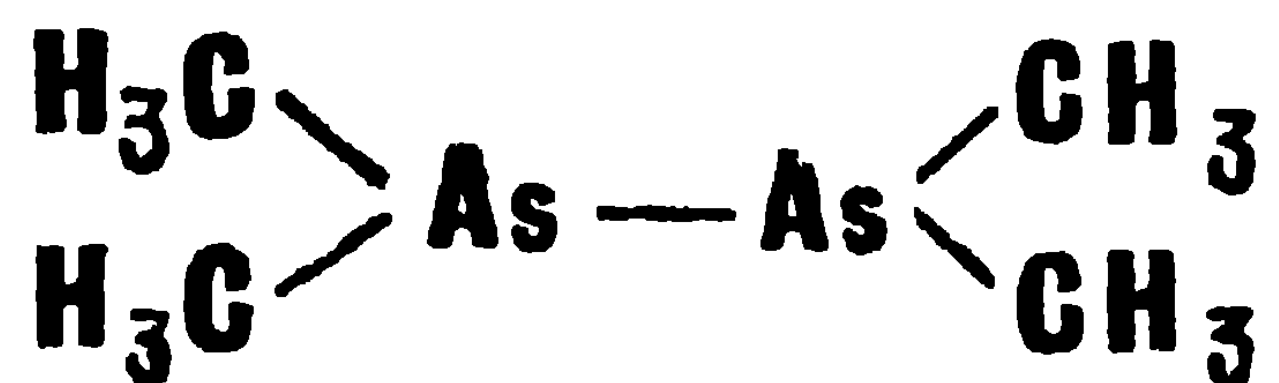
To understand what was so singular about them, it must be recalled that all organic compounds have a very important feature in common: they are based on chains of carbon atoms, straight, branched, or cyclic. True, atoms of some other elements may wedge into these chains. But there are very few such elements (they are called organogens): oxygen, nitrogen, hydrogen, sulphur, and perhaps, phosphorus.





Arsenic is decidedly not one of them.

Cadet's liquid contained a substance called cacodyl (from the Greek "kakodes" meaning ill-smelling). Its constitution is such that the arsenic atoms have wormed themselves firmly in between the carbon atoms, thus:



Organic compounds whose carbon chains include atoms of inorganogenic elements (metals or nonmetals) are now called hetero-organic compounds (organometallic, if the element is a metal).

Thus, Cadet synthesized the first hetero-organic compound in the world.

Nowadays more than 15 thousand such substances are known. Hetero-organic, and especially organometallic chemistry has become a large independent branch of chemistry, one of its more important chapters.

It has bridged the gap between organic and inorganic chemistry and has shown once again how conventional the subdivision of the sciences is in our times.

Indeed, what kind of organic chemistry is it that deals with compounds in which metals, typical representatives of inanimate nature, play the most important part?

And, contrariwise, can it be called inorganic chemistry if a large number of its subject sub-

stances are in many respects purely organic derivatives?

Of major interest to science are organometallic compounds. Their compulsory attribute is the bond between a metallic atom and a carbon atom.

Almost all the metals of the main subgroups of the Big House may be contained in organometallic compounds.

The properties of these substances are very diverse.

Some explode with a terrible force even at temperatures far below zero. Others, on the other hand, possess great resistance to heat.

Some are chemically very active, while others respond reluctantly to all kinds of external influences.

And every last one of them is poisonous, except for the organometallic compounds of germanium. Why the latter are harmless is still a riddle.

The range of applications of hetero-organic compounds is very broad, and practically inexhaustible. They are used in the preparation of plastics and rubbers, in the manufacture of semiconductors and superpure metals; as medicinals and agricultural pesticides and as components of rocket and motor fuels; finally, they are very valuable chemical reagents and catalysts, enabling the successful accomplishment of many important processes.

Our country has a large school of hetero-organic chemists, headed by Academician Alexander Nesmeyanov who was recently awarded the Lenin Prize for his work.

## The Story of TEL

TEL is an abbreviation. It is the name of a compound which is very useful in the practical activities of man. It helps to save petrol. Nobody has ever counted up exactly how many litres of petrol TEL has saved throughout its history, but it doubtlessly amounts to a very impressive figure.

What is this mysterious TEL? A chemist would say: an organometallic compound of the hydrocarbon ethane with the metal lead. Remove a hydrogen atom from each of four molecules of ethane ( $C_2H_6$ ) and add the resulting hydrocarbon radicals (ethyls  $C_2H_5$ ) to a single lead atom, and you get the molecule of a substance with the fairly simple formula  $Pb(C_2H_5)_4$ . It is called tetraethyllead, or 'TEL' for short.

TEL is a heavy liquid slightly greenish in colour with the hardly perceptible odour of fresh fruit, but it is far from harmless. It is one of the most potent poisons.

In itself TEL is nothing to speak of. It is much like any other substance; chemists know of far more remarkable compounds. But add only half of one per cent of TEL to a tank of motor petrol, and the wonders begin.

The heart of any automobile or aeroplane is its internal-combustion engine. Its principle of operation is simple. A mixture of petrol and air is compressed in a cylinder. Then it is ignited by means of an electric spark. An explosion occurs and energy is evolved, making the engine work.

Much depends on the compression ratio of the mixture. The higher this ratio the greater is

the power of the engine, and the more economically is the fuel used. That is the theory. In practice, however, we cannot compress the mixture as greatly as we should like to. This results in "disorders" of the engine: owing to incomplete, non-uniform combustion of the fuel the engine becomes overheated, its parts wear out rapidly, and it consumes petrol at a prohibitive rate.

Improvements in engine design and purer grades of petrol alleviated the "disorder" somewhat, but did not cure it. Motors continued to "knock" and overheat; nonuniform explosions of the mixture (detonations) shortened their service life.

After a great deal of thought scientists came to the conclusion that detonation could be suppressed and the mixture could be made to burn uniformly only by altering the properties of the fuel.

But how?

Thomas Midgley, an American chemist, put a great deal of effort into the study of this question. The first solution he suggested came as a complete surprise. He claimed that if the petrol were coloured red it would be able to absorb more heat and would become more volatile. This would enable stronger compression of the fuel-air mixture.

Midgley "coloured" petrol by adding a little iodine to it. And what was his delight to find that the petrol actually began to detonate less. But when ordinary paint was substituted for the iodine the motor again fell victim to its old troubles.

Hence, colour had nothing to do with it. However, Midgley's chagrin was short-lived. He hit on

the brilliant idea that there probably must be substances, insignificant additions of which could improve the quality of petrol considerably.

Iodine did this only slightly. Other substances, simple or complex, had to be sought. Scientists tested tens and hundreds of compounds. Scientists and engineers worked side by side. Finally the scientists came to the very important conclusion that antiknock agents must be sought among the compounds of elements of high atomic weight. For instance, lead compounds might be tested.

But how can lead be introduced into petrol? Neither the metal itself nor any of its salts are soluble in petrol. The only possible way is to use some organic compound of lead.

It was then that the word "tetraethyllead", TEL, was first pronounced. That was in 1921.

Insignificant additions of TEL to petrol worked wonders. Fuel quality improved sharply. Fuel-air mixtures could now be compressed twice as much as before. This meant that with the vehicle moving at the same speed the petrol consumption would be only half of what it was formerly. Misfires were eliminated from automobile and aeroplane motor operation.

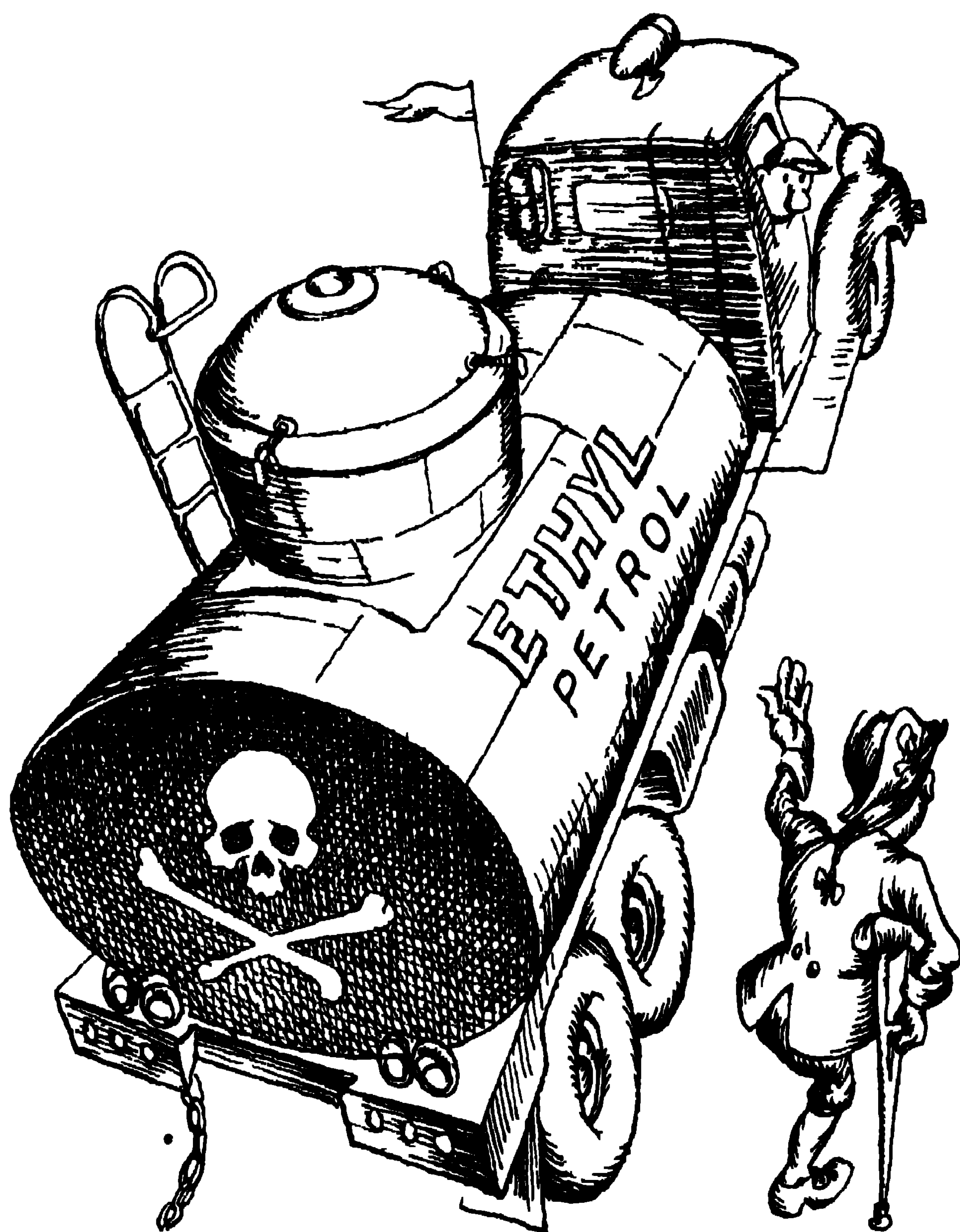
And here is a curious economic note: the world production of TEL is now so high that the natural resources of lead are under hazard.

A very troublesome property of TEL is its high toxicity. You have probably seen tank trucks with the inscription: "ETHYL PETROL. POISON". Petrol containing TEL must be handled with great care.

TEL was the pioneer among antiknock agents, and is still the most important of them. But scien-

tists are giving serious thought to the problem of replacing it by some other substance just as effective, but harmless.

One such substance has already been discovered. It is called CMT. If you want to know what this means, read the next story

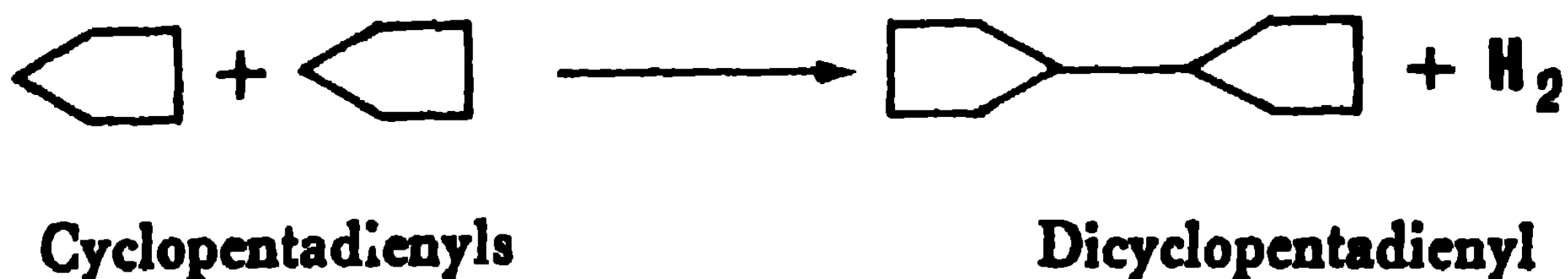




## Unusual Sandwiches

The number of organometallic compounds known today has by far exceeded ten thousand. But some fifteen years ago there was an annoying gap in organometallic chemistry. Chemists could find no way to implant the so-called transition metals in organic molecules. The transition metals are those arranged in the secondary subgroups of the Periodic System. The number of these metals is just under fifty. When chemists did finally succeed in preparing organic compounds of these metals, they were found to be very unstable, kinds of "organometallic freaks."

In 1951, as has happened more than once in the history of science, His Majesty Chance stepped in. The English chemist Pauson gave his student Kealy an assignment, which was anything but complicated. Kealy was to synthesize a hydrocarbon with the rather long name of dicyclopentadienyl. To do this it would be necessary to couple two five-membered carbon cycles. In other words, from two compounds with the formula  $C_5H_5$  he was to obtain one:  $C_{10}H_8$  (it was assumed that two hydrogen atoms would split off).



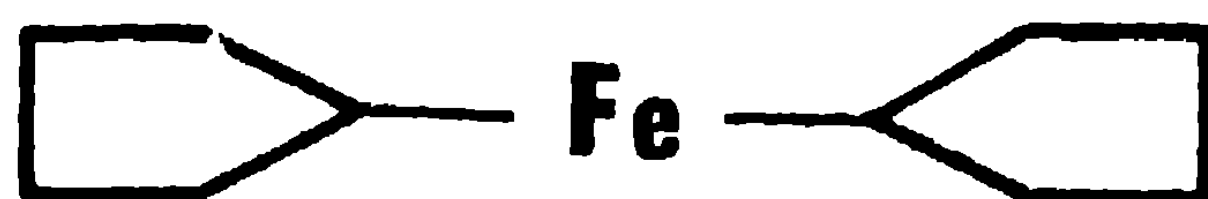
Kealy knew that this reaction could take place only in the presence of a catalyst, and selected ferrous chloride for the purpose.



One fine morning Pauson and Kealy raised their hands in surprise. Instead of the colourless liquid expected the reaction product was beautiful orange crystals, and very stable ones to boot. They could be heated almost to 500°C, which is rather unusual in organic chemistry.

But professor and student were even more surprised when they analysed the mysterious crystals, and they had reason to be. The crystals contained carbon, hydrogen and ... iron. The typically transition metal iron had gone and combined with typically organic substances!

The formula of this organo-iron compound also proved unusual:



Both rings (cyclopentadienes) are flat regular pentagons, rather like two slices of bread with an iron atom between them as the filling. Compounds of this kind are now called “sandwiches”

Ferrocene (so our organo-iron compound was christened) became the first representative of the “sandwich” family.

For the sake of simplicity we have depicted the structure of ferrocene schematically in a single plane; actually, its molecule possesses a more complex spacial structure.

The synthesis of ferrocene was one of the greatest sensations in modern chemistry. Both theoretical and practical workers had to reconsider many of their ideas of the possibilities of organome-

tallic chemistry, that they had hitherto thought infallible.

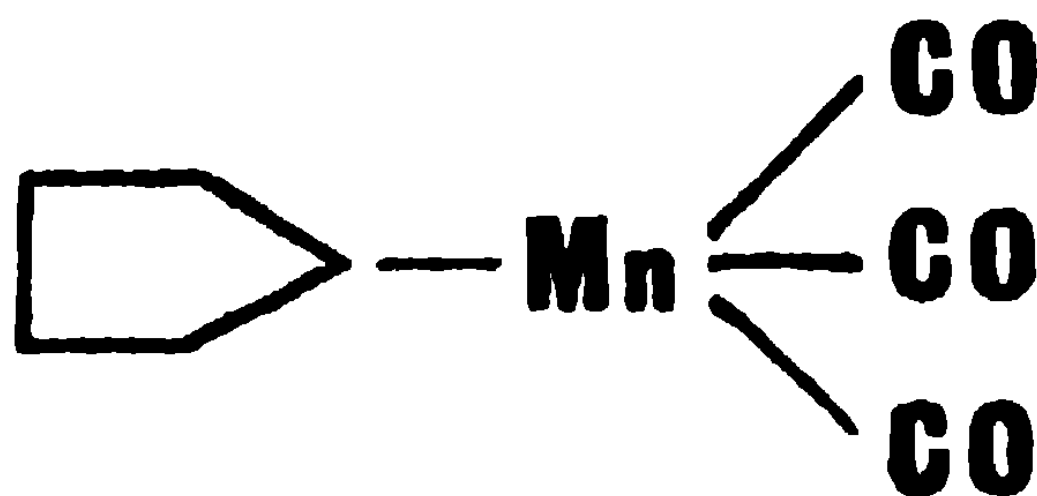
Ferrocene was born in 1951. Today several dozen such ‘cenes’ are known. “Sandwich” compounds have been obtained for almost all the transition metals.

So far they are of interest only to theoretical chemists. As to their practical use, not everything is clear as yet. But...

And now is the time to make the acquaintance of CMT. The full name of this substance is a very long one, but it is easy to remember because it rhymes:

Cyclopentadienyl—  
Manganesetricarbonyl

And the structure of its molecule is easy to write:



Instead of the other “slice of bread” (cyclopentadienyl ring) the filling (the manganese atom) is linked with three molecules of carbon monoxide.

CMT is an excellent antiknock agent, better than our old friend TEL in performance and better also because it is almost harmless. It is now undergoing practical verification from all

aspects. Tank lorries with CMT printed on their sides already run the roads.

Economists have figured out that complete substitution of CMT for TEL may save three billion rubles per year. But the most important advantage is that the air of our towns and cities will be cleaner and healthier.

### **Strange Whims of Carbon Monoxide**

There is nothing tricky about this compound: one atom of carbon and one of oxygen. It is called carbon monoxide. It is very poisonous and takes part in chemical reactions reluctantly; such is a brief character of the substance with the simple formula CO.

...Believe it or not, an event of no great interest occurred in 1916 at a German chemical plant. Somebody decided to make use of a very old steel cylinder (in which a mixture of two gases, hydrogen and carbon monoxide, had been kept under pressure for about five years running). It was opened, the gases were let out and at its bottom was found some light brown liquid with an unpleasant, kind of "dusty" odour.

The liquid proved to be a known, but very rare chemical compound consisting of one iron atom and five molecules of carbon monoxide. Its name, as given in chemical handbooks, was iron pentacarbonyl  $\text{Fe}(\text{CO})_5$ .

(Incidentally, speaking of the fates of scientific discoveries. Iron pentacarbonyl was obtained on exactly the same day, June 15, 1891, by two scientists: Berthelot in France and Mond in

England. Such coincidences are not so frequent, are they?)

An investigation of how the substance had formed in the cylinder showed that nothing supernatural had happened. The hydrogen had made the inner iron surface of the container very active by reducing the iron oxides to the metal. Under pressure, the carbon monoxide had reacted with the iron. After studying the mechanism of the reaction the chemists of the same plant designed an apparatus in which kilograms of the substance could be produced.

As a matter of fact, the pentacarbonyl had found practical usage. It had proved to be not a bad antiknock agent (we seem to be getting them by the dozen, don't we?). A special fuel containing iron pentacarbonyl was produced and it was called Motaline. But motor cars did not use Motaline very long. The pentacarbonyl decomposed too easily into its components, and the resulting iron powder clogged the piston rings of the engines. And just at this time TEL was discovered. . .

Now make a mental note of the easy decomposability of iron pentacarbonyl, and let us turn our attention to other matters for a little while

A large number of carbonyls are now known: of chromium and molybdenum, of tungsten and uranium, of cobalt and nickel, of manganese and rhenium. These compounds have various properties: some are liquids, others solids; some decompose easily, others are fairly stable.

But they all have a common and very curious property: the usual conception of valence does not apply to carbonyls.

It will be recalled that in complex compounds

different numbers of neutral molecules combine with the metal ions. That is why coordination numbers are used instead of valence in the chemistry of complex compounds. The coordination number shows how many molecules, atoms, or complex ions are linked to the central atom.

Carbonyls are still stranger fruits of nature's invention. In them neutral atoms are combined with neutral molecules. The valence of the metals in these compounds must be considered equal to zero because carbon monoxide is a neutral molecule.

This is another paradox of chemistry, and, to tell the truth, it has found no theoretical explanation so far.

And so we now leave off our little excursion into theory.

Practice found the metal carbonyls a dainty morsel.

As catalysts, for one thing.

But carbonyls have much more important uses.

Reverting to the plant in the storehouse of which the old cylinder was found, at the bottom of which a strange liquid was observed that turned out to be iron pentacarbonyl, that...

To make a long story short, that went into production on almost an industrial scale. But once, while the operator in charge of the synthesis apparatus was day dreaming, the pentacarbonyl began leaking out. The vapours of the substance deposited on a steel sheet which happened to be lying nearby. The operator soon discovered the leak and quickly eliminated it, but in doing so he accidentally pushed the sheet off the platform and it fell to the ground floor.

Hunters have a saying: "Once a year even a stick will fire." The steel sheet, which had lain peacefully in the sun for so long, exploded when it hit the ground.

A special "Inquest Commission" held more than one sitting before the experts were able to conclude that the sheet had "exploded" because it had been coated with a very fine iron powder. All finely divided powders in general are likely to explode; for example, explosions have been known to occur with flour dust and powdered sugar.

The iron powder had formed on the sheet as a result of the decomposition of the pentacarbonyl.

The preparation of very fine metallic powders by the decomposition of metal carbonyls strongly attracted the interest of scientists.

They established that such powders have very specific properties. Their particles are very small, just over a micron in diameter. For instance, iron powder can be obtained in the form of fluffy iron "wool" consisting of strong metallic chains. Deposited on a hot surface, carbonyls form a very strong and thin film on it. Such powders and films possess very valuable magnetic and electrical properties and this has gained them extensive usage in radio engineering and electronics.

Carbonyl powders are also attractive to powder metallurgy.

### **Red and Green**

They are both very complex organic substances. Their structural formulas would take up a whole page of our book. Both of them are complex compounds, and unusual ones: their only



metallic atom loses itself, as it were, at the centre of an intricate framework consisting of several cycles. Chemists call such compounds chelate compounds.

By “they” we meant haemoglobin and chlorophyll. The red colour of the blood and the green colour of plants are due to them. These two substances hold the keys to all animate things on Earth.

The “core” of haemoglobin is an iron atom. The blood of different animals contains different haemoglobins, but they all have the same basic structure. The blood of a man contains about 750 grams of haemoglobin.

Haemoglobin transfers oxygen from the respiratory organs to the tissues of the organism.



Chlorophyll has almost the same structure. The difference is that metal atom in it is a magnesium atom. The vital function of chlorophyll is very responsible and complex. It enables the plant to assimilate carbon dioxide from the atmosphere

Chemists are just beginning to learn the essentials of the mechanism of operation of haemoglobin and chlorophyll. Evidently, the central metal atoms, those of iron and magnesium, play a very important part.

But it appears that nature's imagination is very lavish. Iron and magnesium are by no means the only metals that can get inside the porphinic skeleton (such is the name of the organic framework common to haemoglobin and chlorophyll). The metallic "core" may also be copper, manganese or vanadium.

There are creatures on Earth which have blue blood. These are some species of mollusks. The haemoglobin of their blood contains copper instead of iron.

See what remarkable exhibits you can find in our chemical museum!

### **All In One**

In the early thirties of our century geochemists put forward a very interesting hypothesis. According to it any natural sample, be it a piece of stone, a block of wood, a handful of earth, or a drop of water, contains the atoms of every last chemical element known on Earth.

At first it seemed a fantastic assumption. But the eye of analytical chemistry became sharper year by year. New methods of analysis made it

possible to detect millionths and billionths of a gram of substance. And it turned out that if the geochemists' idea was not one hundred per cent correct, still it was not far from the truth.

Indeed, in any stone we may have picked up on a river bank we find silicon and aluminium, potassium and zinc, silver and uranium—almost the whole Periodic System. Of course, most of the elements are present in quantities amounting to not more than a few atoms; but the very fact is interesting in itself.

It would be rather naive to think that all the elements in the stone we found are contained as a single compound. By no means! The stone is an intricate mixture of complex chemical substances. The most important elements in it are silicon, aluminium and oxygen. The content of all the rest of the elements is much smaller, and many of them are present in trace amounts.

So it is in nature. But what about the chemical laboratories? Can scientists prepare a compound whose molecule will contain all the elements of the Mendeleev Table?

Chemists have prepared very complex substances consisting of more than a dozen elements. But not much more. And nobody ever set himself the task of creating a molecular structure wherein all the inhabitants of the Big House are linked by chemical bonds. Not only because they have not had the time to do so, but mainly because it is of little practical interest. It would be very difficult to build such a monstrous molecule.

Difficult, but evidently possible.

It is a rare chemical compound that can be obtained in a single step, by one-stage reaction. If

we set ourselves the aim of building a molecule embracing all the chemical elements, we should have to do it in dozens and perhaps hundreds of stages. Such a complex "building" can be erected only by parts.

We shall not undertake to illustrate on paper the formula of even the simplest version of such a hypothetical "all-element" compound for the simple reason that nobody has ever bothered to think of the ways it could be made.

Without a plan, without drawings no structure can be pictured distinctly. All we can do is use our imagination.

### **The Most Unusual Atom, the Most Unusual Chemistry**

The symbol of this remarkable atom is Ps But in vain will you search Mendeleev's Table for it. It is not the atom of any chemical element

And its lifetime is only an instant, less than a ten-millionth of a second Still, it cannot be said to be radioactive.

Ps stands for positronium Its structure is very simple.

Take a hydrogen atom, the simplest of all the atoms of chemical elements. One electron revolves about a single proton

The positronium atom appears in certain types of radioactive transformations accompanied by the emission of a positron For a very short time the positron forms a stable system with an electron.

In positronium the part of the proton is played by an elementary particle known as the positron.

It is the antipode of the electron. The positron has the same size and the same mass as the electron, the difference being that its charge is of the opposite sign (positive).

A collision between a positron and an electron is the end of both of them. As the physicists put it, they annihilate each other. In other words, they turn into nothing, or to be more exact, into a radiation.

But just before disappearing these two unreconcilable enemies exist side by side for a short instant giving rise to the ghost positronium atom. It is an atom with no nucleus, for the electron and the positron revolve about a common centre of gravity.

Now who could be interested in positronium? Only theoretical physicists, it would seem; or maybe science-fiction writers searching for new types of fuel for their stellar spaceships.

But not long ago a thick book entitled "The Chemistry of Positronium" was published in the USA. This is no science fiction. The book was written by serious scientists and treats of how the investigators make this unusual atom serve their purposes.

During its brief lifetime, positronium is capable of entering into chemical reaction. It reacts especially readily with chemical compounds which have free valence bonds left. These unused vacancies are occupied by positronium atoms.

By means of special instruments chemists can trace the nature of decay of positronium which has got into the molecule of a substance. It is found to decay differently, depending on the structure of the molecule. This enables chemists

to study the intricacies of molecular designs and to solve many sophisticated and controversial problems where other methods have failed

### **Diamond Again**

Diamond is not the most important exhibit in our chemical museum. It is too simple to be unique. Its specific carbon skeleton surprises no one today. Back in the seventeenth century chemists burned diamond crystals in the sun's rays using an ordinary magnifying glass.

Chemists have long had something else on their minds, namely, how to transform graphite into diamond. Both of these are carbon, and all that had to be done was to find a way of rearranging the graphite carbon framework into that of diamond, and the hardest material in existence would thus be made from one of the softest, with nothing removed and nothing added.

A way was finally found. It is a very amusing story and we shall tell it in its place. For the time being we shall remark only that what was needed to prepare artificial diamond was tremendous pressures.

And so, the hero of this story will be pressure. And not an ordinary pressure of a mere one, two or ten atmospheres, but superhigh pressures, when each square centimetre of surface area supports tens and hundreds of thousands of kilograms.

Thus, superhigh pressures make it possible to obtain hitherto unknown substances.

The alchemists knew two varieties of phosphorus, white and red. Now there is a third variety, black phosphorus. The heaviest, the densest, it is

as good a conductor of electricity as many metals. Phosphorus, a typical nonmetal, was converted by superhigh pressures into an almost metallic substance, and a stable one at that.

The example of phosphorus was followed by arsenic, and then by some other nonmetals. And each time the scientist observed striking altera-





tions in properties. The heavy arm of superhigh pressure altered these properties before their very eyes.

From the standpoint of physics nothing extraordinary had happened. Simply the superhigh pressure had rearranged the crystal structure of the elements and their compounds, making them more metallic.

Thus appeared the purely physical term "pressure metallization."

...Astronauts have already visited the Moon. Mars and Venus are now in the order of the day. Then will come the turn of other more distant and still more mysterious worlds. Men will time and again encounter the unusual, the unexpected, the unknown.

But just now we are interested in a particular question

Are the chemical elements the same every where? Does the might of the Periodic Law and Mendeleev's Table extend to all cosmic bodies without exception? Or does the ingenious creation of the Russian scientist apply only on Earth?

We hope we are not annoying the reader with our endless question marks. But really, it is much easier to ask questions than to answer them.

Philosophers are of a definite opinion. They believe that the Periodic Law and the Periodic System are the same throughout the entire universe. That is where they are universal. They are the same, but with one essential reservation: only where ambient conditions do not differ too much from terrestrial conditions, where the temperature and the pressure are not multidigit numbers.

And that is where they are limited.



## **The Unknown Underfoot**

“Before counting the stars have a look underfoot,” runs an Oriental saying.

Do we know our own planet so well? Unfortunately, we know very little about it. We have very little information about the structure of the inside of the globe and about the substances its distant depths consist of.

All we have is an enormous number of various hypotheses and preference can be given to none.

True, oil wells have already gone down seven kilometres! And the depths to be drilled in the near future seem impressive—fifteen to twenty kilometres. But it must not be forgotten that the Earth’s radius is 6,300 kilometres.

There is another Oriental saying: “You have to crack a nut to find out what it tastes like.”

Roughly speaking, our planet bears some resemblance to a nut in structure. A shell—the Earth’s crust—outside, and a kernel—the Earth’s core—inside. The Earth has a very thick layer between the crust and the core, called the mantle.

We know more or less what the Earth’s shell consists of. Rather, not even its shell but just that thin dainty film that envelops a green nut. What the mantle, and the more so, the core, is built like, is still an equation with many unknowns.

There is only one thing that can be said quite definitely. The substances constituting the Earth’s inner strata are quite unusual. The closer to the centre of the Earth, the higher the pressure of the overlying layers. Pressures at the core reach the astronomical value of three million atmospheres.

Incidentally, about the Earth's core. Its structure has been a point of controversy among scientists for more than one century. So many scientists, so many hypotheses.

Some hold that the planet has an iron-nickel core. Others think differently. In their opinion the structural material of the core is the mineral olivine. Under ordinary conditions it is a mixture of magnesium, iron, and manganese silicates. The tremendous pressure inside the core changes the olivine into a sort of metal-like matter. There are scientists who go still further. They claim that the central part of the core consists of hydrogen compressed to complete solidity and therefore possessing unusual metallic properties. There are still others. . .

But we had better stop here. "You have to crack a nut to find out what it tastes like." But it will take a long time to get through to the Earth's core.

We know much less about its structure than about the composition of the atomic nucleus. Now is not that a paradox?

Yes, the unknown is underfoot! A real storehouse of wonders for the chemist: elements in unusual crystalline states; nonmetals transformed into metals; a great variety of compounds whose properties are difficult even to imagine.

The wondrous chemistry of the depths!

But for the time being, as the Soviet scientist A. Kapustinsky pointed out, our chemistry still remains a very "superficial" science.

Does the Periodic System of Elements remain valid in the greatest depths as well? Yes, as long as the electronic structure of the atoms remains

unchanged. As long as the electrons are arranged in the shells they should be in.

But that "status quo" is preserved only for so long.

### **When the Same Is not the Same at All**

No, we have not yet done with superhigh pressure. It is about to bring us a new surprise.

The electronic environment of the nucleus is a rather strong structure. It may lose a few electrons, and then the atom becomes an ion. This process is occurring all the time during chemical interactions.

It may lose many electrons, and finally, it may lose them all so that only the "bare" nucleus is left. This is observed at million-degree temperatures, e. g., in the stars.

But here is a different riddle. Suppose the total number of electrons remains unchanged, but they arrange themselves differently in the electron shells. Such a change is bound to alter the properties of the atom, and hence of the element.

This is, so to say, the text under the illustration. Now for the illustration itself.

You should have no difficulty in picturing the potassium atom. It has four shells. The closest to the nucleus (*K* and *L*) are full: the first contains two, and the second eight electrons. Under ordinary conditions, no more electrons will go into them. But the other two shells are far from complete. The *M*-shell has only eight electrons (though it may have 18), and the *N*-shell has just been started (it has one electron), and this before the previous one is complete.

Potassium is the first atom to display inconsistent, stepwise formation of its electron shell.

But it is not difficult to imagine that instead of entering the fourth shell, potassium's electron might continue the third one (for this shell still has ten vacancies)

Fantastic? Quite—under ordinary conditions. But superhigh pressures give rise to an extraordinary situation.

Under superhigh pressures the electron shells surrounding the nucleus contract greatly and the outer electrons can “fall” into the underlying incomplete shell.

For example, suppose the outer electron in the fourth shell of the potassium atom were imbedded in the third, making nine electrons in its *M*-shell.

What would this amount to? The atomic number of potassium (19) would be the same as before, and so would the number of electrons. In a word, no transmutation of elements would have occurred.

Just the same, our old friend the alkali metal potassium would no longer be our old friend. It would be a stranger with three shells instead of four and with nine electrons in its outer shell instead of one. And so the chemical properties of “neopotassium” would have to be studied anew.

What these properties would be we can only guess, because not a speck of “werewolf potassium” has ever been available for investigation.

At still higher pressures, the elements following potassium would also lose their usual aspect. Stepwise filling of electron shells, the law in the Mendeleyev Table, would here no longer be ob-

served. As long as one shell were incomplete, the following one would remain empty.

...This would also be a periodic system, but not Mendeleev's. Its inhabitants (except for the elements of the first three periods) would be different. Its "alkali" metals would be copper and promethium and its "noble gases" nickel and neodymium, in which the corresponding outer shells would be completed.

This is what "deep-seated" chemistry may turn out to be! Unusual valences, strange properties, surprising compounds...

Attractive? Oh, yes! Real? Who knows... What is wanted here is again probably some "crazy" idea, since the preparation of an entirely new type of matter is involved. Even if it does exist at superhigh pressures, it should reassume the form of the conventional elements under ordinary conditions.

The question is how to preserve or "freeze" this transition. If we succeed in solving this question, we shall have in fact a new chemical science, a No. 2 chemistry.



**With Its Eyes**





## **A Word on the Use of Analysis**

Mikhailo Lomonosov once said: "Chemistry stretches wide its arms..." Two hundred odd years ago his ingenuity sensed the significance of this science for future generations.

The twentieth century has brought this out vividly. Chemistry is now a "many-armed creature." Not every academician can even enumerate all its branches right on the spot. And new ones keep appearing almost every year.

But there is one thing without which any of these chemical "arms" would hang lifeless.

That thing is chemical analysis.

It has helped chemists to discover very many of the elements existing on Earth.

It has enabled them to establish the constituent parts of chemical compounds, both simple and complex, from table salt to proteins.

It has deciphered the compositions of rocks and minerals and has helped geochemists to account scrupulously the Earth's reserves of chemical elements.

Chemistry owes much to analysis, in particular, its becoming an exact science. Analysis is the first helper in various spheres of human activity, as is seen from an untold number of examples.

For instance, suppose iron is being smelted from its ore in a blast furnace. Its properties depend largely on the amount of carbon in the resulting metal. If there is more than 1.7 per cent carbon in it, we get cast iron; the interval from 1.7 to 0.2 per cent represents various grades of steel, and if the metal contains less than 0.2 per cent carbon it is called wrought iron.

What is the difference between iron and steel, brass and bronze? How much copper is there in blue vitriol? Is there much potassium in the mineral carnallite? Only chemical analysis supplies the answers to these and similar questions. Two main questions confront it: what elements are contained in the substance under investigation, and in what proportion? The former is the scope of qualitative, and the latter, of quantitative analysis.

As to how many different kinds of analyses there are, no one, not even an experienced specialist, can say right off the bat

### **To Make Good Gunpowder**

Who invented gunpowder? Legend says that it was the German monk Berthold Schwarz.

Gunpowder is not difficult to make: all you have to do is mix sulphur, saltpetre and finely powdered charcoal in definite proportions. But the components must be of high quality.

How can their quality be judged?

In the old days gunpowder makers tested saltpetre by tasting it.

Here is a curious procedure for analysing saltpetre by taste, found in the archives: "Saltpetre that is salty and bitter is no good; only if it bites the tongue and some sweetness can be felt, is the saltpetre good."

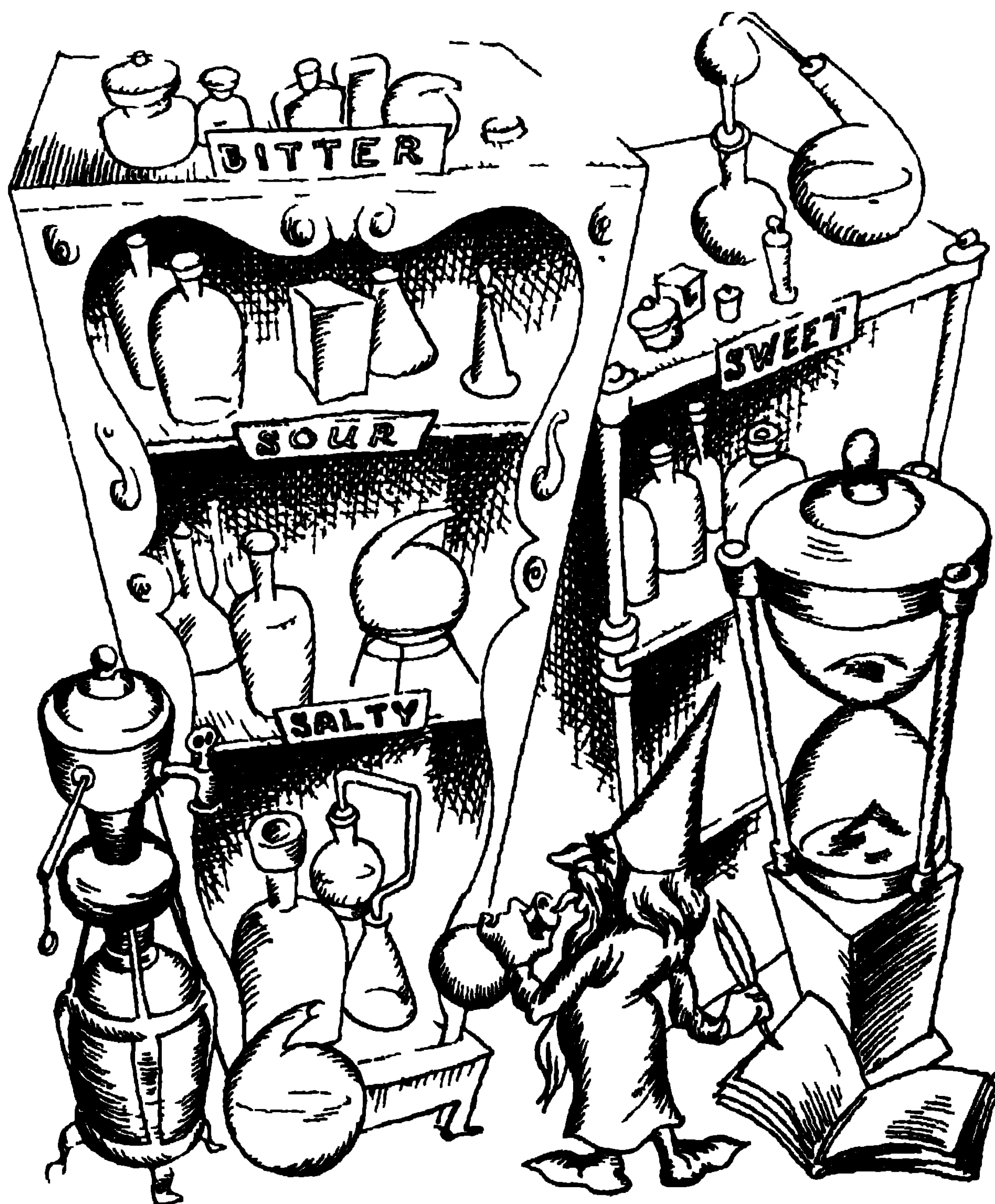
One could say of a good gunpowder maker that he had "eaten a peck of salt," couldn't one?

The method of testing sulphur was still more singular.

A piece of sulphur taken in the fist was

brought close to the ear. If a slight cackling sound could be heard, the sulphur was considered suitable. Otherwise it was discarded as impure.

Why does pure sulphur cackle? Its thermal conductivity is very low. The fist warms the sulphur and different parts of it acquire different



temperatures. Stresses arise in the sulphur, and being brittle, it breaks up into small pieces, making slight cackling sounds as it does so. The thermal conductivity of impure sulphur is much higher and it is therefore much stronger. Such is the scientific grounding, so to say, of chemical analysis by ear.

To make a long story short, the principal analytical instruments of the chemists of the past were their sense organs. This fact is even reflected in the names of some simple and complex substances. For example, beryllium formerly used to be glucinum, because its salts have a sweetish taste. The name glycerine also comes from the Latin for "sweet". And natural sodium sulphate is called mirabilite, which means "bitter."

### **How Germanium Was Discovered**

In the beginning of March 1886 D. Mendeleev received a letter which read:

"Dear Sir,

Allow me to present you with the reprint enclosed herein of a report from which it is evident that I have discovered a new element named 'germanium'. At first I thought this element would fill the gap between antimony and bismuth in your remarkable and profoundly composed periodic system, and that the element would coincide with your eka-antimony, but the facts indicate that here we have to do with eka-silicon.

"I soon hope to tender you more detailed information on this interesting substance; today I content myself with informing you of a very pro-

bable new triumph of your ingenious investigation and take the opportunity to express my deep respect for you

Faithfully yours,  
Clemens Winkler,

Freiberg, Saxony,  
February 26, 1886 "

Not in vain, it appears, did Henry Cavendish almost a hundred years before the discovery of germanium, repeat time and time again that "everything is determined by measure, number, and weight" In analysing argyrodite, a rather rare mineral discovered not long before in Saxony, Clemens Winkler found it to contain mainly silver and sulphur with small quantities of iron, zinc and mercury But what surprised him was that the percentages of all the elements found in argyrodite added up to only 93 and stubbornly refused to make 100

What could the elusive 7 per cent be? The methods of analysis of most of the elements known by that time were well worked out and not one of them should have escaped the chemist's eye. Then Winkler made the daring assumption that since these 7 per cent had escaped him with the existing analysis procedures, they must belong to an unknown element. His assumption was fully confirmed By slightly changing the procedure of the analysis Winkler isolated the elusive 7 per cent and proved them to belong to a new element, unknown at that time, which he named germanium in honour of his native land.

Gravimetric analysis played an important part in the discovery of one more element, namely,



argon, a representative of the zero group of Mendeleev's Periodic System.

In the early nineties of last century the English physicist Rayleigh undertook a determination of the density of gases, and hence of their atomic weights. All was well until the investigator came to nitrogen. Here strange things began to happen. A litre of nitrogen separated from air weighed 0.0016 gram more than the same amount of nitrogen produced from chemical compounds, the kind of compounds having no effect on the final result. The ill-starred litre of nitrogen obtained from ammonium nitrite, nitrous or nitric oxides, urea, ammonia, or other compounds, invariably proved to be lighter by the same amount than atmospheric nitrogen.

Not having found the reason for this strange difference, Rayleigh published an article in the London journal "Nature," describing his results. Soon the chemist Ramsay responded and the investigators combined their efforts in an attempt to solve the riddle. In August 1894 they reported the discovery of a new element, the cause of Rayleigh's first failures. Its content in the air was found to be about one per cent.

Thus ordinary gravimetric analysis helped scientists to discover new elements. Not a single chemical laboratory can get along without it even today. In the long run ordinary weighing helps to determine the percentages of elements in complicated compounds and minerals. Of course, it must be preceded by painstaking chemical operations of separation of the elements from one another.



## Light and Colour

On each major Soviet holiday you hear the Moscow Radio announcer say: "Order of the Minister of Defence. . . 'In Honour of . . . I order a salute shall be fired in the capital of our country, Moscow, in the capitals of the Union Republics and in the Hero cities' . . ."

The sky is magnificent during the salute with yellow, green, and red lights flashing through it under the thunder of the salvoes.

The tradition of celebrating holidays by salvoes and fireworks is very old. The art of pyrotechnics was known in China as far back as two thousand B. C. But only comparatively recently did it occur to scientists to utilize coloured flames for chemical analysis.

Just over a hundred years ago the German physicist Kirchhoff noticed that the salts of different metals coloured a colourless gas-burner flame differently. Sodium salts make the flame yellow, calcium salts colour it carmine-red, barium salts—green, etc.

Kirchhoff soon realized that this offered a quick and reliable method of detecting chemical elements in substances. However, his glee was premature. All was well as long as pure salts were used. But if salts of, say, sodium and potassium were mixed, the violet colour of potassium was practically indiscernible against the background of the bright yellow burner flame (due to the presence of sodium).

The physicist Bunsen came to the aid of the chemist Kirchhoff. He suggested examining the burner flame with the mixture of salts introduced

into it through a special instrument called a spectroscope. The main element of this instrument is a prism which resolves the white light passed through in into a spectrum, i.e., into its components. The name "spectroscope" means "to observe a spectrum."

The idea was a great success. Unlike other sources of light, the gas-burner flame into which the salt under test was introduced, gave a linear spectrum instead of a continuous one, and the lines of the spectrum were always in strictly constant positions. Thus, a sodium salt introduced into the flame caused two closely spaced intense yellow lines to appear in the spectrum. Potassium salts gave rise to one red and two violet lines, etc.

Kirchhoff and Bunsen found that the lines of any particular chemical element always appeared in exactly the same positions in the spectrum. No matter whether sodium was introduced into the flame as the chloride, the sulphate, the carbonate, or the nitrate, the positions of the sodium lines were always the same. Even mixing the sodium salts with other salts, say, of potassium, copper, iron, strontium, or barium, did not affect the positions of the sodium lines.

Inspired by their discovery Kirchhoff and Bunsen worked indefatigably. They tested a very large number of elements and compounds "in the flame". After some time they drew up a list of the chemical elements with the characteristics of their lines in the spectrum. Now scientists could unerringly analyse many complex mixtures of substances.

Thus was born spectroscopic or spectrum analysis. It proved not only an excellent method for

determining various known chemical elements qualitatively in mixtures. It also helped to discover new elements: rubidium, cesium, indium, and gallium. And when it was found that the intensity (brightness) of the lines depends on the amount of substance present in the mixture, spectrum analysis took up an honourable position among quantitative methods.

### **Chemical Analysis of . . . the Sun**

In anticipation of the solar eclipse of 1868 astronomers, as always, prepared a great deal of equipment. This time the list included a spectroscope, the instrument which had not long before enabled the discovery of several new elements.

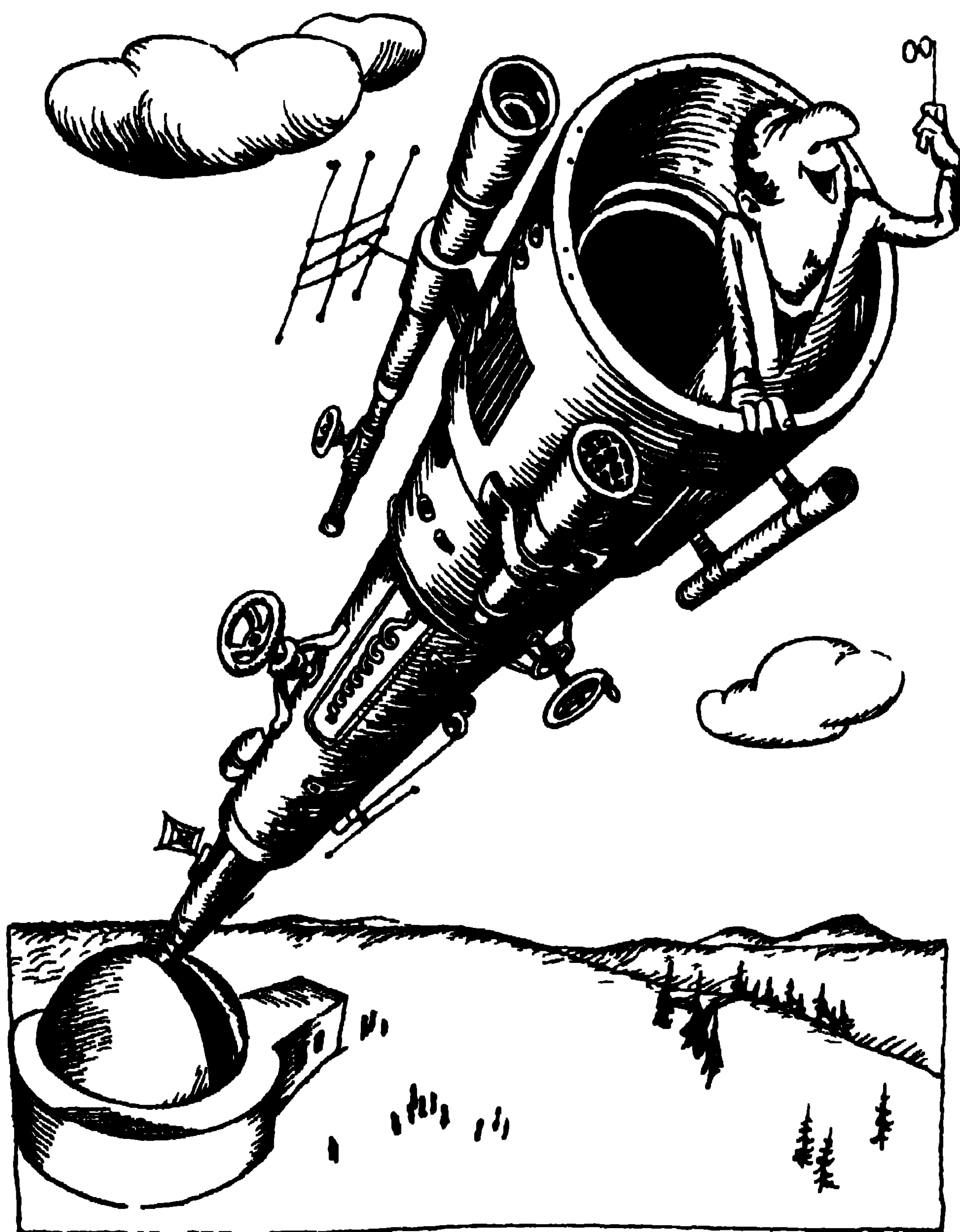
The eclipse passed, and everything settled back to normal. But on July 25, 1868, the French Academy of Science received two letters simultaneously, one from the shores of distant India from the Frenchman Janssen, and the other from England, from the Englishman Lockyer. The contents of both letters were the same almost word for word: each of the authors informed the Academy that he had, by means of spectrum analysis, discovered an element on the Sun that was unknown on Earth. It gave a yellow line in the spectrum, resembling the sodium line in colour. But this line had nothing to do with sodium.

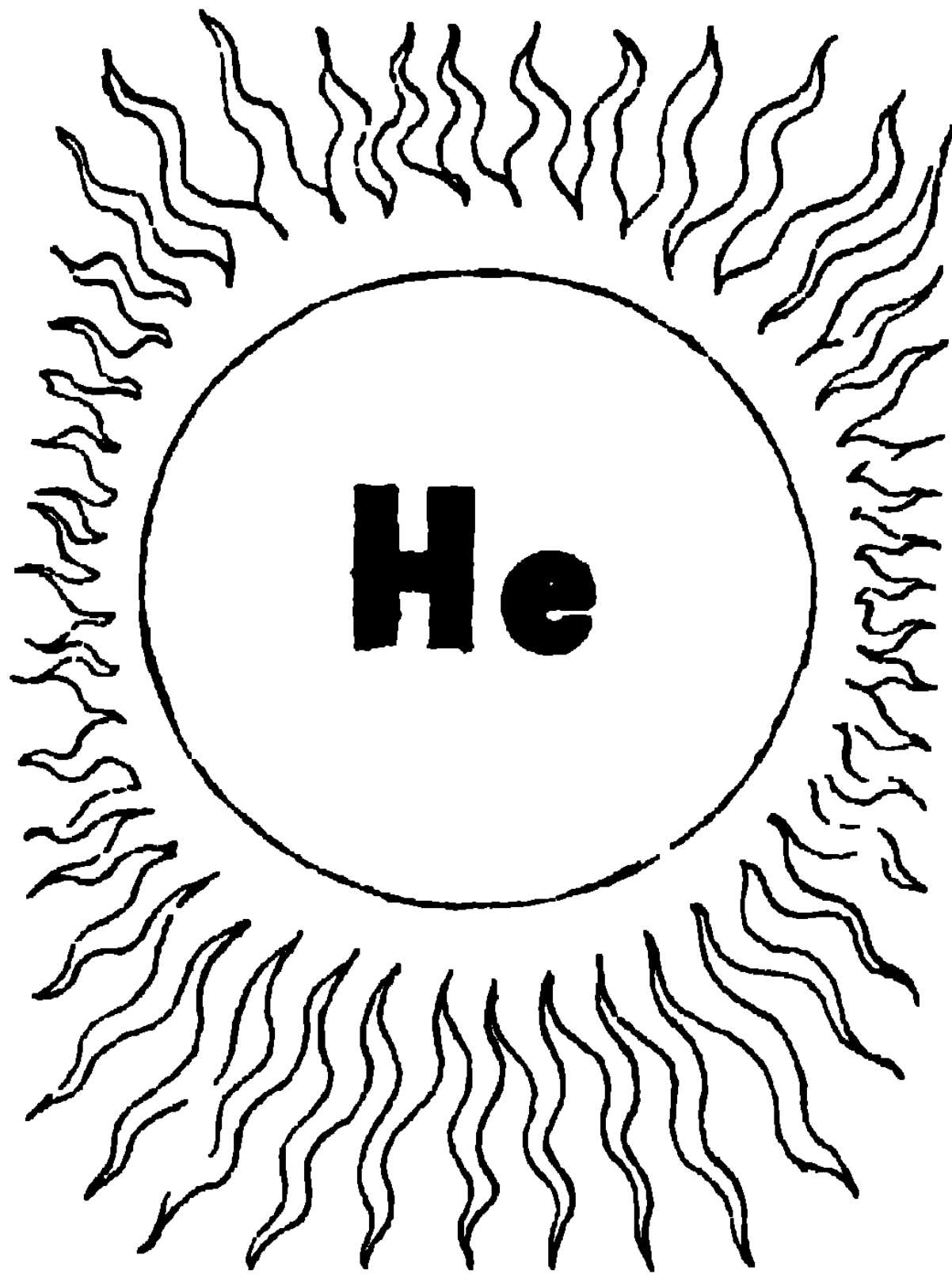
The esteemed assembly of scientists was greatly astonished. Janssen and Lockyer had not only succeeded in "analysing" the Sun, but were claiming to have discovered a new element as well!

On Earth helium (such was the name given to

the “solar element”) was discovered only 27 years later, in 1895.

In honour of this great event, the discovery of a method which made possible investigation of the secrets of the distant cosmic bodies, the French Academy passed a decision to coin a spe-





cial medal. The method was indeed worth a special medal. By any other method at least a very small amount of substance must be available to perform the analysis with. Spectrum analysis defies all distances.

After the discovery of the “solar element” scientists more than once trained their spectrographs (recording spectrosopes) on the Sun, and it meekly told them all about itself.

After the Sun came the turn of other stars, near and distant. The glitter of stellar atmospheres reached the spectrosopes on Earth and in the silence of their laboratories scientists studied the intricate palisade of all kinds of spectral lines. In the heavenly bodies scientists found the elements that were already known on Earth.

Only eighty years later did solar helium pass on the relay of scientific surprises to the element technetium, the one that occupied box 43 in the Mendeleev Table. A ghost in terrestrial ores, technetium was first discovered in the spectra of certain stars, and only after that were traces of the element found on Earth. In the stars technetium is by no means a rare element. It forms in them continuously as a result of nuclear reactions.

No more new elements were discovered on the Sun or in any of the stars, and probably never will be. The universe is uniform: the Earth, the Sun, the planets and stars and all the heavenly bodies in general consist of the same chemical elements.

But the curious thing is that the "balance" of chemical elements in the skies is different from what it is on Earth. Not oxygen and silicon predominate in outer space, but hydrogen and helium. The amount of these first two representatives of the Periodic System in the universe is many times greater than that of all the rest of the elements taken together. See what a surprising paradox stellar chemistry brings us: our galaxy is primarily a kingdom of hydrogen.

### **Waves and Substance**

The number of colour hues in nature is infinite. Chemists know that as well as anybody else. And not infrequently the fantastic gamut of colours leaves them nonplussed.

"What colour is, say, a solution of neodymium nitrate?"



"Pink," replies the chemist.

"And what colour will a solution of trivalent iron turn if potassium thiocyanate is added to it?"

"Red."

"And what colour does phenolphthalein turn if a solution of alkali is added to it?"

"Crimson."

We could continue almost indefinitely: very many chemical reactions involve colour of a definite hue. Probably if we were to name a dozen more compounds whose solutions are coloured some shade of red, we should get entirely confused. They say that artists and textile workers who dye fabrics can distinguish about two dozen shades of red. Now that is what acquiring an eye for colour means!

But such an "intuitive" way of distinguishing hues and shades is of little use to chemists. Even a solution of the same substance may have an infinite number of shades depending on its concentration. How could they all be remembered?

There appear to be people on Earth who can distinguish colours with their eyes blindfolded by using their fingertips. Doctors say that such people have highly developed cutaneous vision. The famous writer Jonathan Swift wrote sarcastically of the Laputan Academy of Sciences that the blind mixed various colours there to ironize on the "scientific" subjects they studied.

Today the sarcasm of the English satirist is no longer appropriate. Now chemists can name the colour of a solution without seeing it. They do it with the aid of what is known as spectrophotometry. This distinctive method of analysis derives



its name from an instrument called the spectrophotometer with which the colour of a chemical compound or its solution can be analysed.

Isaac Newton passed a narrow sunbeam through a glass prism and discovered that white light is complex. We have all of us probably seen a rainbow. The colours of the rainbow are the components of white light. Newton observed such a rainbow when he passed the sunbeam through the prism. This rainbow is called a spectrum.

But what is light? It is electromagnetic vibrations or waves. Each wave has a definite length (usually denoted by the Greek letter " $\lambda$ "). The wavelength exactly characterizes any colour or shade. For example, chemists say: "a red colour of the wavelength 620 millimicrons" or: "a red colour of the wavelength 637 millimicrons" (a millimicron is one thousandth of a micron, or one millionth of a millimetre). This eliminates the need to give definite names to the separate shades, such as "crimson," "red," "bordeau," "scarlet," "vermilion", etc. Just name the wavelength and all the scientists in the world will know quite definitely the colour and shade meant. Each compound has now received a kind of "certificate" with " $\lambda$  equals so much" filled in under the item "colour". Believe us, it is a very reputable document.

But this is only half the matter. The colour of a compound depends on the wavelengths of the rays it absorbs and those of the rays it transmits. For instance, if a solution of a nickel salt is green, it absorbs light of all the wavelengths except those which correspond to the green hue. A yel-

low solution of potassium chromate is transparent only to yellow rays.

The spectrophotometer gives beams of light rays of definite wavelengths and makes it possible to determine how they are absorbed by various substances. A great number of compounds, organic and inorganic, have been investigated with spectrophotometers.

Besides visible light there is light that is invisible, that the human eye does not see. These kinds of light "from the beyond" lie outside the limits of the visible light spectrum, and are called ultraviolet and infrared rays. Chemists have learned to use them too. They studied the spectra of various chemical substances in the ultraviolet and infrared ranges and discovered a very interesting phenomenon. They found that each chemical compound (or ion) has its own distinctive absorption band spectrum. Each substance has its own "colour (infrared or ultraviolet) certificate."

Absorption spectra can be used not only for qualitative, but for quantitative analysis as well. This is due to the fact that in many cases the higher the concentration of a chemical compound in a solution, the more intense its colour, i.e., the stronger it absorbs colour of a definite wavelength. Hence, by determining the absorption of light by a solution (one usually says, "by determining its optical density"), one can easily find the concentration of any particular element.

### **It's Only a Drop of Mercury that Does It**

From hoary antiquity comes the saying: "All things of genius are simple."

Only once was the Nobel Prize awarded for a discovery in the field of chemical analysis. The discovery was made in 1922 by Yaroslav Heyrovský, the famous Czech scientist. Since then Prague has become a kind of Mecca. Numerous pilgrims have travelled to Prague to learn Heyrovský's new method, polarography.

Today over a thousand papers are published yearly all over the world on polarographic analysis. The ABC of the method is as follows. Some mercury is placed at the bottom of a glass beaker containing the solution in which the concentration of a given substance has to be determined. The mercury layer serves as an electrode. Drops of mercury falling at definite intervals from a capillary into the beaker are the other electrode.

A source of electricity is connected to the electrodes. This should cause electrolysis in the solution. But electrolysis will occur only if the potential on the mercury drop is high enough. If the potential is small, no current will flow through the circuit. It is increased until the ions contained in the solution begin to discharge. Then current begins to flow through the circuit.

If there are ions of different elements in the solution, each species will be discharged at a different potential value characteristic of those particular ions.

The chemists plot graphs, marking off the potential values along the abscissa axis, and the currents that appear along the ordinates. The resulting curve resembles a staircase, each step corresponding to the discharge of a definite species of ions.

The staircase obtained is compared with a

standard curve, one which has been plotted beforehand for a solution containing known concentrations of known substances.

Thus the solution can be analysed qualitatively and quantitatively at the same time. By means of special devices the analysis can be made automatic.

The first epithet that occurs to you respecting the polarographic method is elegant. But elegance is not the only thing. Polarography is simple, rapid, and precise; moreover, it surpasses most other methods of analysis in these qualities. For example, zinc can be determined polarographically with as little as a millionth of a gram of zinc chloride in one cubic centimetre of solution. This analysis takes less than ten minutes.

Heyrovský's original idea has now been perfected and many new versions have been suggested. One of these is adsorption polarographic analysis which has a very high sensitivity. It can readily be used to determine organic substances in concentrations as low as thousand-millionths of a gram per cubic centimetre of solution.

Where is polarography needed? Why, practically everywhere: for automatic production control, and for analysis of minerals and alloys. Polarography gives an idea of the contents of vitamins, hormones and poisons in the organism. Physicians are even thinking of using polarography for early diagnostics of cancer.

### **A Chemical Prism**

By a strange coincidence, this scientist's name and profession are consonant with his discovery.

He was a botanist and his name Mikhail Tsvet. Tsvet is the Russian for colour. The botanist Tsvet was interested in chlorophyll which, as we know already, is the colouring matter of green leaves.

But Professor Tsvet also knew many chemical procedures. In particular, he knew that there were substances (adsorbents) which could retain (adsorb) many gases and liquids on their surfaces.

He ground a leaf into a green paste and treated it with alcohol. The paste lost its colour, which meant that all its colouring matter had been extracted by the alcohol.

Then he filled a glass tube with chalk moistened slightly with benzene; into this tube he poured the solution containing the chlorophyll.

The upper layer of the chalk powder turned green.

The scientist washed the chalk in the tube with benzene, adding it drop by drop. The green ring budged and then began to move downwards. And then—oh wonder!—it separated into several bands of different colours. There were a yellow-green, a green-blue and three yellow bands of different shades. It was a curious sight that the botanist Tsvet observed. And this sight proved a most important find for chemists.

It indicated that chlorophyll was a complex mixture of several compounds, different, though close, in molecular structure and properties. What is now called chlorophyll was only one of them, true, the most important one. All these substances had now been separated from one another by a very simple method.

All of them had been adsorbed by the chalk,

but each in its own way. The strength of retention of each compound by the surface of the chalk powder was different. And when the benzene (the eluant) passed through the tube, it carried off the substances in a definite sequence. First those that were held less strongly, and then those that were retained more strongly. This caused the separation.

Like a prism resolves solar light into the spectrum colours, so did the column of adsorbent (the "chemical prism") split up the complex mixture of substances into its component parts. This new method of analysis discovered by Tsvet in 1903 was christened chromatography by its author. This word comes from the Greek for "colour writing."

Today the method of chemical "colour writing" is one of the most important instruments in all analytical laboratories the world over.

But the fates of many scientific discoveries are inscrutable. Some are forgotten, sometimes for many years, only to shine afterwards on the scientific horizon like stars of the first magnitude. So was it with chromatography. It was actually remembered only in the forties, and nobody ever regretted this.

### **How Promethium Was Discovered**

Strictly speaking, it was discovered many times, this element with the atomic number 61. And each time it was given a different name: illinium, florentium, cyclonium. But each time the discovery proved false, and the name of the stillborn became history.

Then scientists proved that there simply was



none of the sixty-first element on Earth. Not due to some strange whim of nature by which it had deprived the Periodic System of one of its representatives, but because all the isotopes of element No. 61 are radioactive, very unstable, and had long since decayed into isotopes of its neighbouring elements.

Finally, it was produced artificially in 1945, in the course of operation of a nuclear reactor. Fission of the nuclei of uranium, the reactor "fuel", results in a large number of fragments, these being nuclei of lighter elements. They include promethium (now the real name of this elusive element).

After pondering for a space theoretical physicists might have signed this report. But chemists would have to "feel" promethium with their hands, and to see with their eyes at least a tiny speck of the new metal. or at least its compounds.

However, it would have hardly been possible to separate more than tenths or even hundredths of a gram of element No. 61 from the mixture of fragments of uranium fission.

Is that so little? Chemists had more than once had to deal with still smaller amounts of substance, and they had been successful.

The difficulty was one of a different nature. Promethium is a rare-earth element, and we have already spoken of the resemblance in this family. Now the mixture of nuclear fragments contained a substantial amount of promethium's closest neighbours, neodymium and samarium.

It was from them primarily that promethium had to be separated, but that was no easy job! Chemists who devoted their lives wholly to the



rare earths performed a real scientific feat. It was torment—there is no other word for it—to separate the fourteen twins and to obtain each of them separately.

(The French chemist G. Urbain decided to prepare pure thulium. And he did. But it took him five years and he had to carry out over fifteen thousand monotonous and very tedious chemical operations.)

Of course, separating pure promethium was easier, but not much. It must be remembered that it is radioactive and decays rapidly. And so it might have happened that there was nothing left of it by the time it was separated.

Hence, quicker methods were needed, methods by which it would not take years, or months or even weeks to separate the lanthanides, but not more than a few hours. Chemistry knew no such methods.

Then it was that chromatography was remembered.

...Tsvet's separating tube (it now goes by the more sedate name of chromatographic column) is filled with an adsorbent (not chalk as before, but special ion-exchange resins). A solution of salts of the rare-earth elements is passed through the resin layer. Though they resemble each other greatly, the lanthanides are not identical. Each forms a complex compound with the resin. These compounds differ in stability, and moreover, in a definite order. Lanthanum, the first in the family, makes the strongest compound; the last, lutetium, forms the weakest.

After this the resin is washed with a special solution. The drops of the solution encompass the

resin grains and wash off the ions of the rare-earth elements, as it were—again in a strict sequence.

And solutions of pure rare-earth salts begin to issue from the column drop by drop: lutetium salts first, and lanthanum salts last.

It was by this method that the American scientists J. Marinsky, L. Glendenin and C. Coryell separated promethium from neodymium and samarium. And it took them only a few hours.

### **Aromas of a Wild Strawberry Patch**

...A glade in a pine forest. A hot day in July. And strawberries, strawberries everywhere—ripe, rugged, bright red berries, so tasty, they melt in your mouth.

But what do they smell of, these strawberries? You must confess that you have never stopped to think about it. You just enjoyed the aroma of the pine forest, the smell of the sunny glade.

But odour is a very complex phenomenon. There is a whole science of odours. Scientists still have to work out a uniform opinion as to why some substances have a strong odour while others have hardly any; why some odours are pleasant, and others disgusting.

There is no doubt that the odour of a substance is related to the structure of its molecules. But how? That is what we cannot say for certain. There is no strict physical theory of odours as yet.

Chemists have an easier time of it. They can identify the different molecules “responsible” for various odours, and can tell you exactly what strawberries smell of.

The odour of strawberry is a very complex mixture of ninety-six odours differing over a wide range. Even the most experienced perfumer might well envy nature for being able to create such splendid "strawberry" perfume.

How were scientists able to "dissect" this "strawberry" perfume?

By the method of gas-liquid chromatography.

The adsorbent in this method is specially prepared silicon dioxide,  $\text{SiO}_2$ , moistened with a nonvolatile liquid. The moving medium is a noble gas (e. g., argon). And that is just about all.

Otherwise, a glass tube may simply be moistened with the nonvolatile liquid. The tube must be very long. To "catch" the entire aroma of fresh strawberries researchers had to use a tube ... 120 metres long.

Of course, it had to be wound into a coil and placed in a special apparatus called a thermostat



where the temperature could be raised slowly and evenly. This was necessary because the different components of strawberry odour differ in volatility, some evaporating more readily, and others less. The components arranged themselves in a definite sequence along the tube. Then they were forced out by passing argon through the tube. At the outlet a complicated apparatus registered the passage of the different substances. The odour of strawberries proved to contain ninety-six of them though their weight totalled only about  $10^{-12}$  gram!

Chemists have investigated quite a number of very complex natural substances by this method. How many components do you think petroleum contains? No less than two hundred and thirty! Moreover, they have not only been counted but each of them have been identified.

### **The Death of Napoleon: Legend and Reality**

According to the official version Napoleon Bonaparte I died on the Island of St. Helena on May 5, 1821. The cause of his death was cancer of the stomach, a disease which brought the former ruler of half the world to his grave in less than half a year. The coroner's statement was signed by Dr. Antommarchi.

Though this version was firmly established, few people believed it, and not without reason.

Many of the great emperor's retainers insisted to the end of their days that Napoleon had not died a natural death but had been poisoned.

And Bonaparte himself, in dictating his will a

week before his death, said: "I have been killed by the British oligarchy and its hired assassins."

But what could Napoleon have been poisoned by? More than enough poisons of various kinds were known in the last century, but the unknown murderer would hardly use just any of them to assassinate the emperor.

What was needed was a tasteless poison, so that the victim should not become suspicious. It would have to be not a very strong one, one that would accumulate slowly in his organism and kill him gradually. Such a poison could have been arsenic.

And so there appeared another version, namely, that Bonaparte had been poisoned by arsenic.

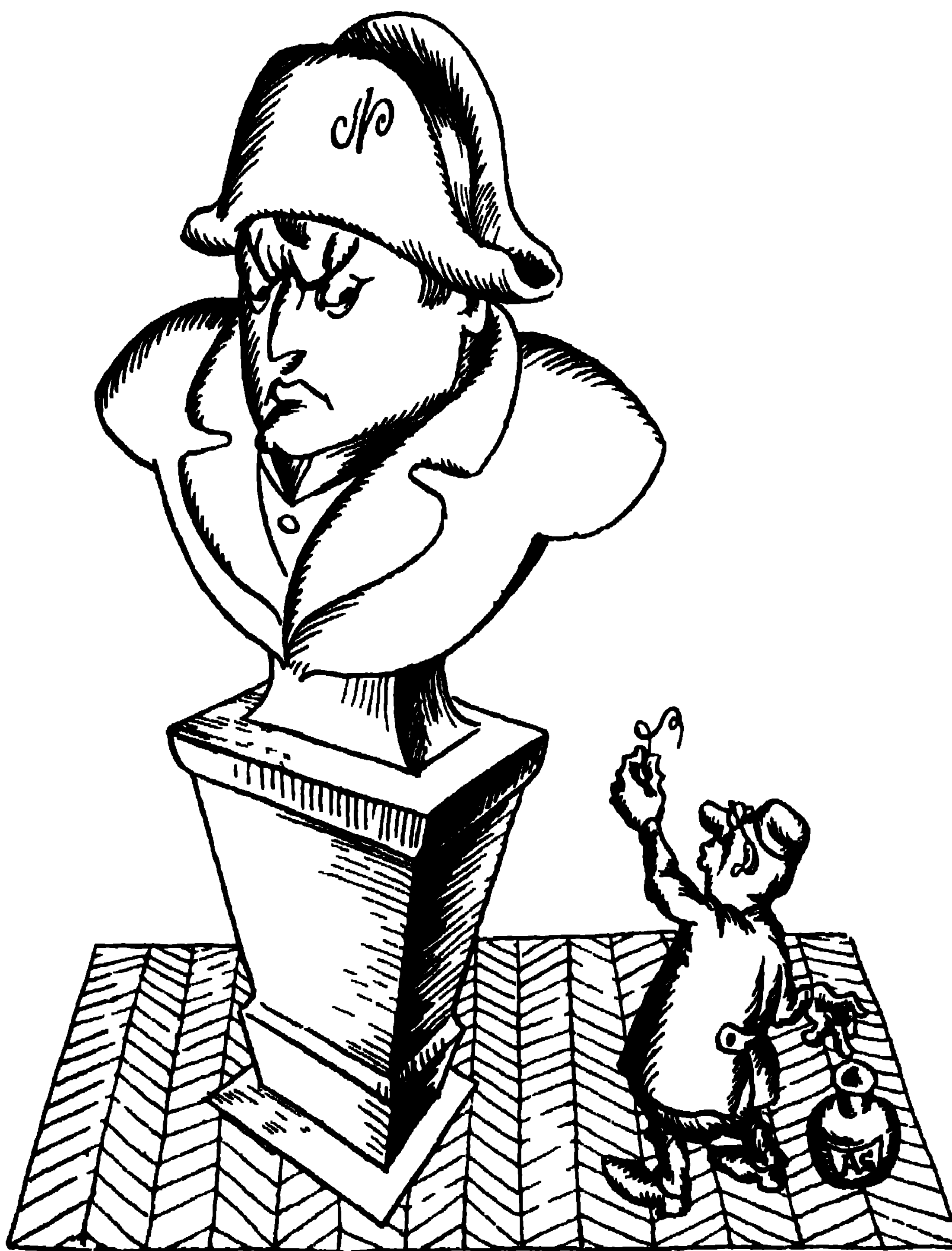
But how to prove it? No end of assumptions could be made, but what was needed here was unquestionable proof. No witnesses were left. To exhume the emperor's remains from his tomb for an investigation seemed sacrilege.

Nevertheless, 140 years after the sad event an unusual investigation was started at the Scotch town of Glasgow concerning the case of the violent death of Napoleon. The case was pleaded by two physicians, Drs. Smith and Forshufwood.

They started by sending a strange request to many of the world's museums, inquiring whether they had in their collections a . . . tuft of hair of the great Frenchman. It took some time before fortune finally favoured the investigators. They received a few hairs cut off Napoleon's head several hours after his death.

The physicians knew that arsenic taken up by the human organism gradually accumulates in the hair. If they detected it in Bonaparte's hair, . . .

But this is more easily said than done. The amount of arsenic in the hair is very small indeed. Chemical methods of analysis could have been used, of course, but their sensitivity was too low to exclude the possibility of error, and here one had to be absolutely sure.





Then the Swedish physicist Wassen joined in on the investigation.

The precious hairs were carefully sealed in an aluminium cylinder and placed for a few hours in a uranium reactor.

When the hairs were retrieved and subjected to special measurements, it became quite clear that Napoleon had indeed died of arsenic poisoning. The amount of arsenic in his hair was thirteen times above the normal content. Moreover, the arsenic had been administered gradually, in small doses.

How had the scientists succeeded in establishing the true cause of Bonaparte's death? How could they detect arsenic without using a single chemical method?

### **Activation Analysis**

Natural arsenic is a very stable element. In any case, nobody has ever detected radioactivity in it.

Arsenic has another peculiar feature. It is what one might call a "lone" element. Many of the others are mixtures of two, three, or more isotopes. For example, tin consists of ten different kinds of atoms and they are all found in nature.

But arsenic is single. Its nucleus contains 33 protons and 42 neutrons, and this combination is a very stable one.

But if an extra neutron is in some way induced to enter this nucleus, its stability vanishes, and a radioactive isotope of arsenic forms, an isotope that can be detected without chemical methods. All that is needed is an instrument for registering radioactive emission. The larger the amount of



active arsenic, the more intensive will be its radiation.

Such is the basic principle of the simple but very important method of activation analysis. It enables the determination of infinitesimal amounts of substances, fractions of a gram represented by numbers with 10 or 12 zeros after the decimal point. To do this the object under study had only to be irradiated with a beam of neutrons, and the intensity of the radiations emitted by the resulting radioactive isotopes measured.

That was how the historians discovered the circumstances of Napoleon Bonaparte's death. Is it not a splendid example of aid proffered by the exact sciences!

To modern analysts activation analysis is an all-seeing eye. It easily discerns what hardly any other analytical method can detect.

Pure germanium is commonly known to be an excellent semiconductor. But if it contains only a few atoms of such an impurity as, say, antimony, as little as one antimony atom per million million germanium atoms, in fact, the semiconducting properties of germanium entirely disappear.

That is why germanium has to be checked very carefully for impurities, and this can be done only with the aid of activation analysis.

And so neutrons speed on their way to a plate of germanium. Chemists know that it contains some amount of antimony. Maybe so little that it can be neglected, but maybe so much that the "pure" germanium will have to be rejected. The atomic nuclei of germanium and antimony react differently to neutrons. The former allow them to

pass-by quite indifferently, but the latter absorb them avidly. For this reason only radioactive isotopes of antimony are formed. The rest is done by radiation counters. Then we can tell for sure whether there is much or little antimony in the germanium.

### **How to Weigh the Imponderable**

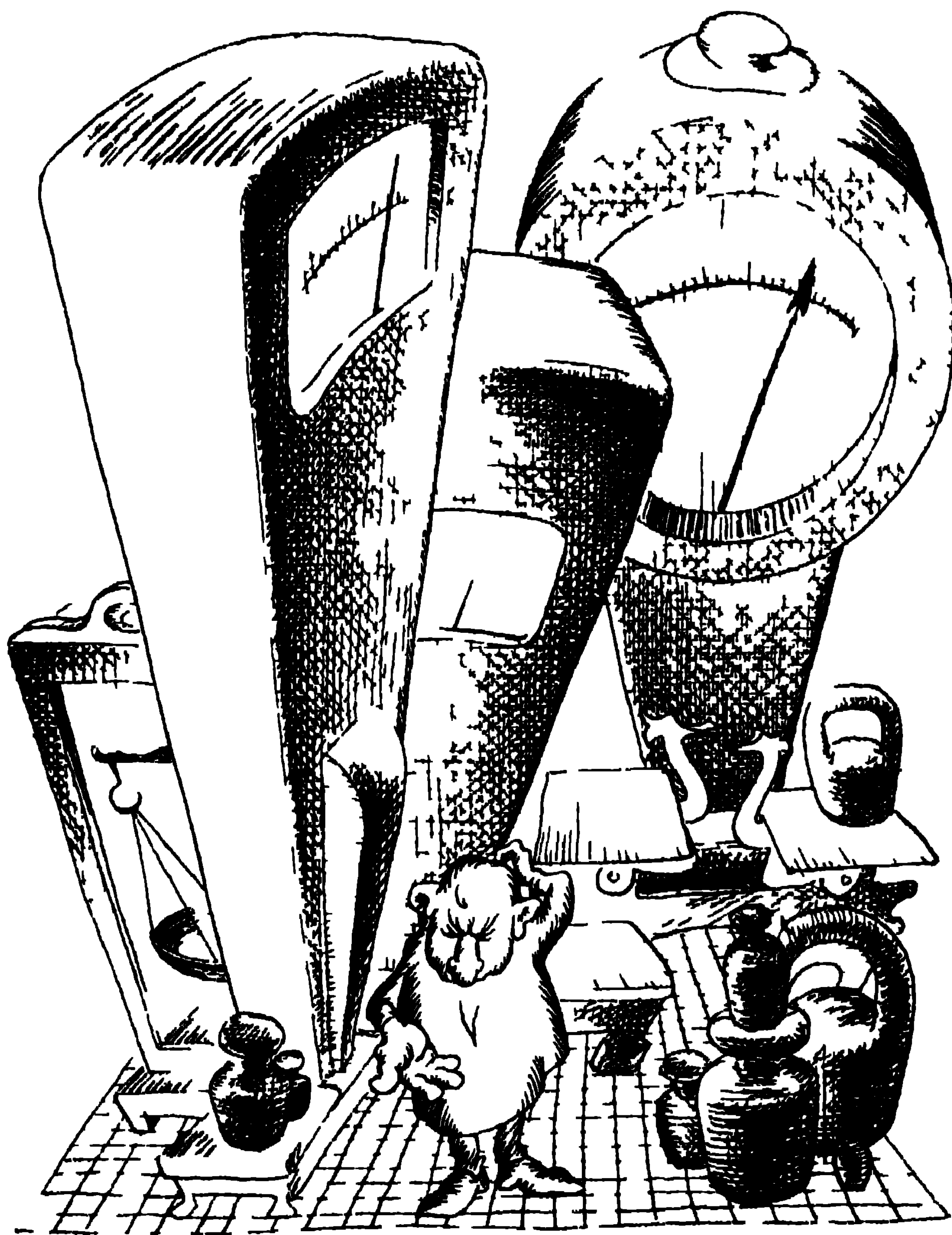
Is 500 micrograms much? Let us see. One microgram is one thousandth of a milligram, or one-millionth of a gram. Hence, 500 micrograms is five ten-thousandths of a gram, or half a milligram. If we are talking about water, 500 micrograms is half of a cubic millimetre, about three times less than the volume of a pin-head. But what if the substance is ten times as heavy? Then its volume will be ten times less. Such an amount of substance is even difficult to discern. What could one do with it? Only examine it under the microscope, and nothing more.

Still, five hundred micrograms of plutonium, and no more, was the amount available to American scientists in 1942. But having only this truly imponderable amount, they succeeded in studying the principal properties of the element. Furthermore, they studied them so thoroughly that a year later a large plutonium plant was being planned.

But during all kinds of chemical reactions chemists have had to resort repeatedly to weighing...

Now what is there so complicated about a balance? A balance is a balance. Even an analytical microbalance which makes weighings to a

hundredth of a milligram is fairly simple in design. However, such accuracy has long since ceased to satisfy scientists. Consequently, at the turn of our century a balance was designed for weighing to one ten-thousandth of a milligram. Incidentally, the English physicist William Ramsay used just such a balance to weigh about 0.16 cu-



bic centimetre of radon and thus to confirm Rutherford's hypothesis of the mechanism of radioactive decay of radium.

But even this balance was not the limit. Somewhat later the Swedish chemist Hans Patterson constructed a balance which could weigh to ten-thousandths of a microgram, i.e., to  $6 \times 10^{-10}$  gram! Such accuracy is difficult even to imagine. The sensitivity of a modern ultramicrobalance is one two-millionth of what it can weigh.

Super-precise weighing, weighing of the imponderable, is one of the achievements of a new science called ultramicroanalysis. And there are other no less important achievements it can boast of.

Methods have been devised by means of which various chemical operations can be carried out with very minute volumes of substances, down to one ten-thousandth of a millilitre (cubic centimetre) to an accuracy which in a number of cases is no worse than about one ten-thousandth of a microlitre ( $1 \times 10^{-10}$  litre).

Ultramicrochemical methods find extensive usage not only in biological and biochemical investigations, but especially in the study of the artificial transuranium elements.

### **The Chemistry of Single Atoms**

There were times when chemists bewailed the difficulty of studying the properties of a new element available only in milligrams.

Since then the "criterion of smallness" has had to be revised more than once. In 1937 the Italian scientists Perrier and Segrè quite successfully stu-

died the properties of the just then obtained element No. 43, called technetium, having at their disposal only one ten-thousand-millionth of a gram of this new representative of the Periodic Table.

Their experience was of benefit to others. When working with the transuranium elements chemists had to forget entirely such weight units as grams, milligrams or even micrograms. "Imponderable, invisible amounts"—such were the terms that appeared on the pages of scientific papers devoted to the transuranium elements. The deeper investigators delved into this region of the Periodic System, the greater were the difficulties they encountered.

Finally came the turn of the hundred and first element, called mendelevium in honour of the great Russian chemist.

Since the new transuranium element received a name, scientists must have been quite convinced that it had actually been obtained.

It had been comparatively easy to calculate the conditions under which one could hope to synthesize element No. 101. There was not much difficulty in writing the equation of the corresponding nuclear reaction. Which isotope of the new transuranium element would form could also be foreseen.

Such was theory. But what had been obtained in practice needed confirmation, to prove that isotopes of precisely the hundred and first element, and none other, had formed as a result of the nuclear process.

What followed was fantastic. "During one experiment of synthesis of the hundred and first

more than one atom of the new element cannot be expected to form"—such was the verdict of strict physical and mathematical reasoning, and so it turned out in reality. Only one single atom, an unknown atom, announced its birth. But was it an atom of the hundred and first element?

Sensitive radiometric instruments enabled determination of the half-life of the atom, but not of its chemical nature.

And in general, is it possible to study even the chief chemical properties of a single atom?

Chromatography came to the rescue.

Now follow our reasoning closely. The hundred and first element must belong to the actinide family. In many of their properties the actinides resemble the elements of another similar family of elements called the lanthanides. Separation of the lanthanides was accomplished by ion-exchange chromatography, the individual lanthanides coming out of the mixture in a strict sequence, the heavier ones first, and then the lighter ones.

In the actinide series the hundred and first element was to follow einsteinium (No. 99) and fermium (No. 100). If we wish to separate einsteinium, fermium and element No. 101 chromatographically, the last-named element should appear in the first drops of the liquid issuing from the chromatographic column.

Seventeen times scientists repeated the experiment of mendelevium synthesis. Seventeen times they used ion-exchange chromatography to establish the chemical nature of the new man-made atom. And in each case the mendelevium atom appeared exactly in the drop of solution in



which it was to have appeared according to theory. Formerly only fermium and einsteinium came out in these drops.

Hence, the atomic number of mendelevium is 101 and it is a typical actinide in properties.

### **Is There a Limit?**

Everything in the world has an end, except the universe, which had no beginning and will have no end. Therefore, generally speaking, there is a limit to analysis, and there is no doubt about that. If we learn to determine the chemical nature of separate atoms of elements or molecules of a chemical substance, we may consider that the limit has been reached.

But that is not what we wanted to point out. As late as the forties of our century, some twenty-five years ago, chemists could analyse most impurities if their content in the principal substance was of the order of 0.01-0.001 per cent, and this suited almost everyone. But nowadays science and technology progress at such a terrific rate that by the early sixties it was already necessary to determine about one thousand billionth ( $10^{-12}$ ) of a per cent of an impurity. But at that time we were only approaching such sensitivities in determining individual elements. At present there are already several elements and their compounds which we can determine in such quantities, thanks, primarily, to the methods of activation analysis, gas chromatography and mass-spectrometry, which enable scientists to determine such "trifles."

The requirements imposed on impurity analy-



sis will continue to mount steadily. Academician I. Alimarin, a renowned Soviet scientist, believes that the requirements for materials with respect to purity tend to such a limit where it will be necessary to determine single atoms of the impurity, i.e., amounts of substance of the order of  $10^{-23}$  gram. This difficult task will have to be coped with by physicists and chemists jointly. It has been solved so far for radioactive atoms. We can already determine the radioactive atoms of some chemical elements singly. However, the sensitivity of determination of the stable atoms and their compounds is still far from the limit. And here methods of analysis still await those who will succeed in "filling in" this "blank."

### **An Amazing Number**

In their calculations scientists often have to do with what they call constants, i.e., numerical values characterizing some quality or property. We wish to draw your attention to one of them.

It is called Avogadro's number, after the famous Italian scientist who put this constant into use. Avogadro's number is the number of atoms in a gram-atom of any element.

It will be recalled that a gram-atom is the number of grams of an element equal to its atomic weight. For example, a gram-atom of carbon is (roundly) 12 g, that of iron, 56 g, and of uranium, 238 g.

The number of atoms in each of the quantities named is exactly equal to Avogadro's number.

Written on paper it can be represented appro-

imately by a "one" followed by twenty-three naughts; more exactly, it is  $6.025 \times 10^{23}$ .

That is how many atoms are contained in twelve grams of carbon, fifty-six grams of iron, or two hundred and thirty-eight grams of uranium.

Avogadro's number is so monstrously large that it is difficult even to imagine.

Still, let us try.

The human population of the globe is about three thousand million. Now suppose all the inhabitants of the Earth decided to count up the number of atoms in a gram-atom of some element. Suppose each man worked eight hours daily and made one count each second.

How much time would it take for all the inhabitants of the Earth to count up all the  $6.025 \times 10^{23}$  atoms?

A very simple calculation, which you can easily do yourself, shows that it would take about 20 million years. Impressive, isn't it?

The immensity of Avogadro's number is evidence that the idea of the omnipresence of all the chemical elements has a sound footing. We can always detect at least a few atoms of any chemical element everywhere.

Avogadro's number being so large, it is obvious that all attempts to obtain an absolutely pure substance containing no impurities at all would be futile. It is utterly impossible to catch a single atom of an impurity among  $10^{23}$  atoms without introducing new impurities in the process.

Indeed, a gram of, say, iron, contains about  $10^{22}$  atoms. If it contains only one per cent (10 milligrams) of copper atoms as the impurity, that still makes not less than  $10^{20}$  atoms. Even if

the impurity content is reduced to one ten-thousandth of a per cent, the number of atoms of the impurity per  $10^{23}$  atoms of the principal substance remains  $10^{16}$  atoms. If the impurity includes all the elements of the Periodic System, there will be an average of  $10^{14}$ , i.e. one hundred trillion atoms of each element



# **Chemistry Spreads Wide .**



## **Diamonds Once More**

A raw, unfaced diamond is the champion of "all the minerals, materials, etc." in hardness. Modern engineering would have a hard time without diamonds.

A faced and ground diamond becomes a brilliant, which has no equal among gems.

Greyish-blue diamonds are especially prized by jewellers. They occur "once in a blue moon" and this makes their price truly fantastic.

But after all, gem diamonds are not so very important. If only there were more ordinary diamonds, so that we should not have to worry over every tiny crystal!

Alas, there are very few diamond deposits on Earth, and still less rich ones. One of them is in South Africa and it still gives up to ninety per cent of the world's diamond production outside of the Soviet Union. In this country a very large diamond-bearing region was discovered about ten years ago in Yakutia, and now diamonds are produced there on an industrial scale.

The formation of natural diamonds required extraordinary conditions, namely, immense temperatures and pressures. Diamonds were born in the deeper layers of the Earth's crust. At places diamond-bearing melts subsequently broke out on to the surface and froze, but this happened very rarely.

But can't we get along without nature's help? Can't man make diamonds himself?

The history of science knows of numerous attempts to produce diamonds artificially. (By the way, one of the first "fortune seekers" was Hen-



ri Moissan, the first to isolate fluorine in the free state ) Not one of them was successful Either the method was fundamentally wrong, or the experimenters did not have at their disposal equipment which could withstand the combination of exceedingly high temperatures and pressures

Only in the middle fifties of this century did modern engineering finally find the key to the problem of producing artificial diamonds As might have been expected, the starting material was graphite It was subjected simultaneously to a pressure of 100 thousand atmospheres and a temperature of about three thousand degrees Now diamonds are produced in many countries of the world

But in this case chemists could only rejoice together with everybody else They played but a minor part, most of the credit for this accomplishment being due to the physicists

However, the chemists scored in another way, having helped substantially to perfect diamonds

To perfect diamonds? Can anything be more ideal than diamond? Its crystal structure is the most perfect in the world of crystals It is the ideal geometric arrangement of carbon atoms in diamond crystals that makes them so hard

Diamonds cannot be made any harder, but a substance harder than diamond can be made Chemists have created the starting material for producing such a substance

There is a chemical compound of boron and nitrogen called boron nitride It is nothing much to look at, but what puts one on the alert is its crystal structure, which is the same as that of graphite. That is why boron nitride has long been

known as "white graphite." True, nobody has ever tried to make pencil of it. . .

Chemists found a cheap way to synthesize boron nitride. Physicists put it to severe tests involving hundreds of thousands of atmospheres and thousands of degrees. . . The logic they followed was quite simple. Since "black" graphite could be changed into diamond, why could not a substance similar to diamond be obtained from its "white" counterpart?

The result was borazon, a substance that exceeds diamond in hardness. It leaves scratches on smooth diamond faces, and can withstand higher temperatures: it is not so easy to burn borazon.

Borazon is still too expensive. It will take some effort to bring its price down. But the most important part has already been done. Man has again proved more capable than nature.



...It was reported not long ago that Japanese scientists have succeeded in preparing a substance considerably harder than diamond. They subjected magnesium silicate (a compound consisting of magnesium, silicon, and oxygen) to a pressure of 150 tons per square centimetre. For obvious reasons the details of the synthesis are not advertised. The newborn "king of hardness" has no name as yet. But that does not matter. What does matter is that unquestionably diamond, which has for centuries headed the list of the hardest substances, will in the near future be far from the top of this list.

### **Endless Molecules**

Everyone knows what rubber is. It is balls and galoshes. It is the hockey puck and the surgeon's gloves. It is automobile tyres and hot-water bottles, waterproof raincoats and hoses.

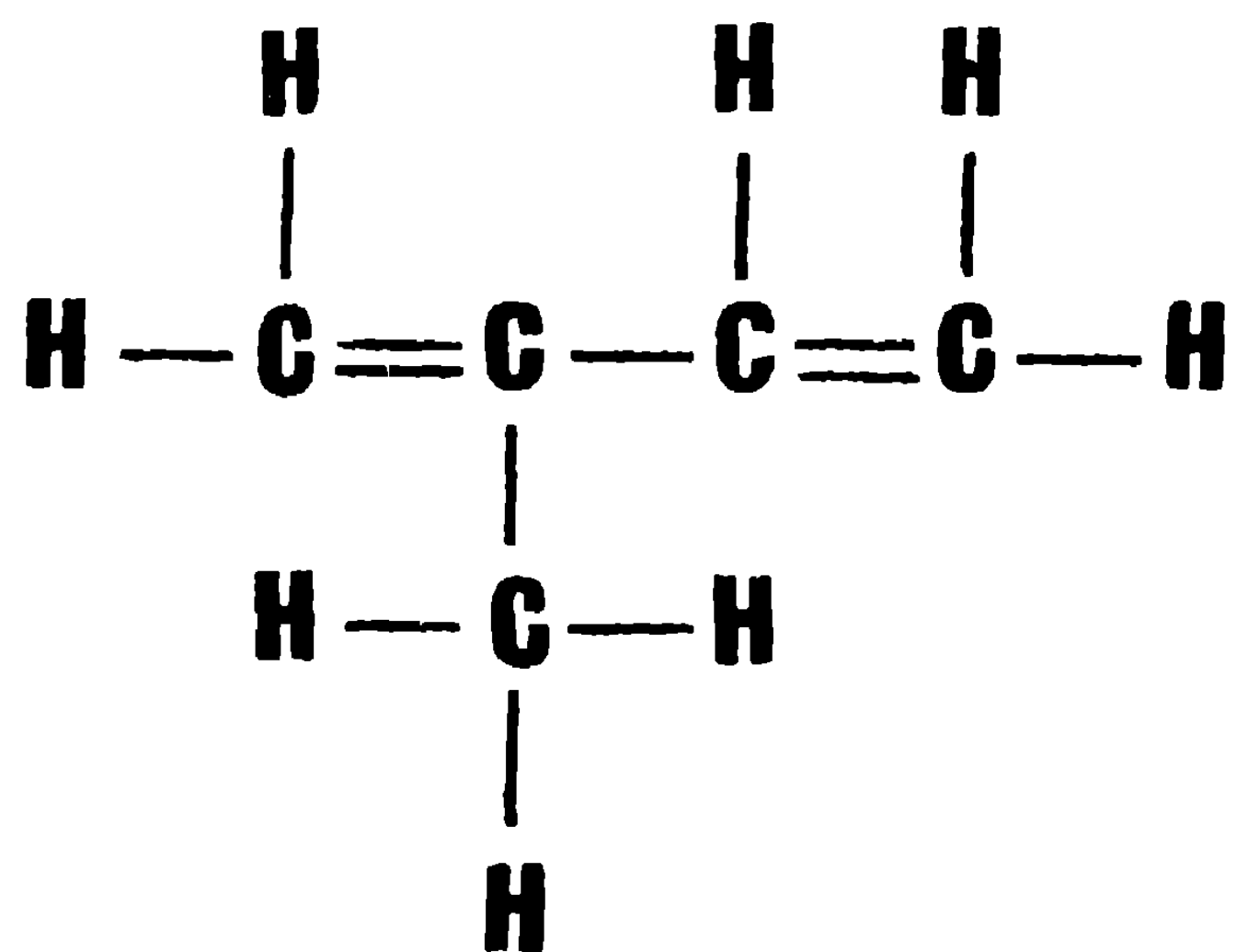
Rubber and rubber goods are put out nowadays by hundreds of factories and plants. A few decades ago all rubber goods were made of natural rubber, otherwise called caoutchouc. The word "caoutchouc" comes from the Tupi \* "caou-uchu" meaning "tears of the Hevea." The Hevea is one of the most important trees whose sap is used to make rubber.

Many useful things can be made from rubber, and it is too bad that its production is very labour-consuming, and that the Hevea grows only

\* Tupi is the language spoken by a group of South American Indian tribes inhabiting mainly the valley of the Amazon.—*Tr.*

in the tropics. All this has made it impossible to meet the demands of industry for the natural raw material.

Here again chemistry came to the rescue. First of all chemists tried to find the answer to the question of why rubber is so elastic. After studying the "tears of the Hevea" for a long time they finally found the answer. It proved that the rubber molecules have a very peculiar structure. They consist of a large number of recurring identical units linked into immense chains. Of course, a long molecule consisting of about fifteen thousand units, can bend in all directions and is elastic. It was found that the units making up the chain are molecules of the hydrocarbon isoprene,  $C_5H_8$ , which has the following structural formula:



It would be more correct to say that isoprene is a sort of initial natural monomer. In the course of polymerization the isoprene molecule undergoes a slight change: the double bonds between the carbon atoms open, and the freed bonds link up the units into the gigantic rubber molecules.

The problem of producing synthetic rubber drew the attention of scientists and engineers long ago

At first glance the job did not seem very tricky  
One had to produce isoprene and then make it polymerize, i.e., make the isoprene units combine

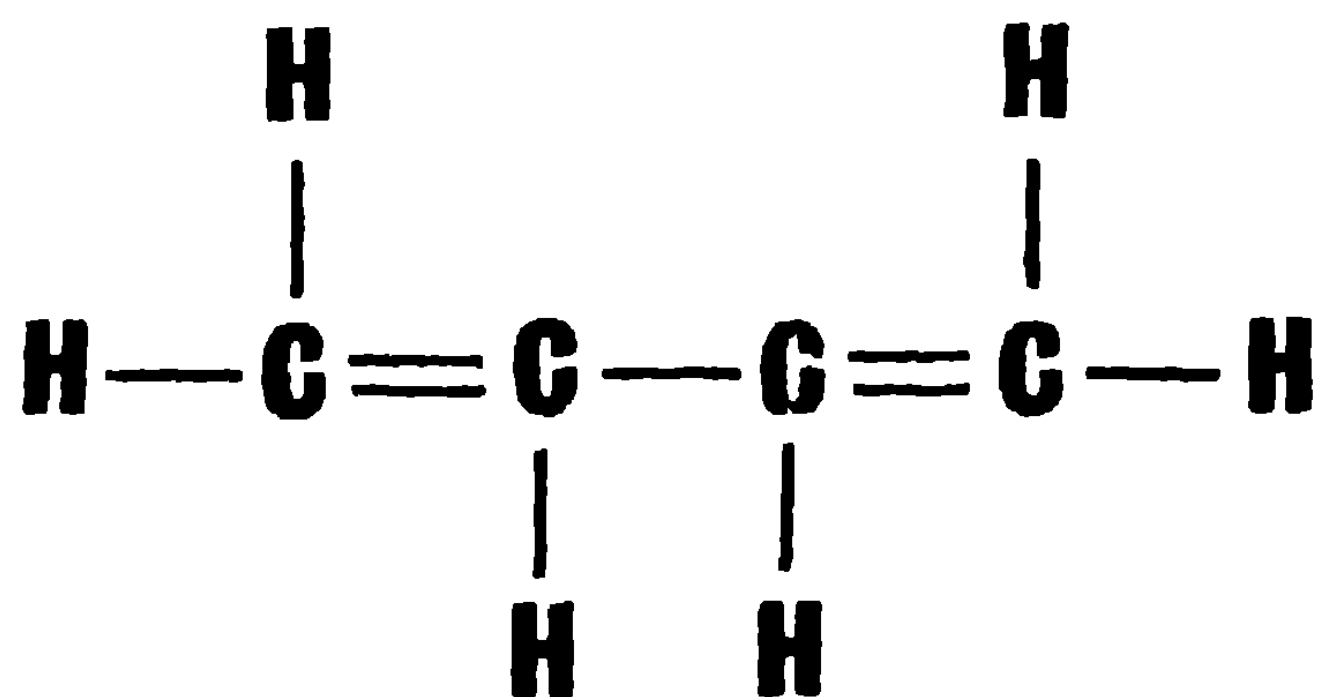


into long and flexible chains of artificial rubber.

But reality was disappointing. Chemists succeeded with some difficulty in synthesizing isoprene, but when it came to polymerizing it rubber did not result. The units combined with each other, but did so haphazardly rather than in a definite order and the result was artificial products which resembled rubber slightly but differed from it in many respects.

And so the chemists had to invent methods of making the isoprene units connect up into a chain in the right way

The world's first industrial synthetic rubber was produced in the Soviet Union. Academician S. Lebedev chose a different substance, butadiene, for the chain unit:



It greatly resembles isoprene in composition and structure, but its polymerization is easier to control.

At present quite a large number of synthetic rubbers are known (they are now often called elastomers to distinguish them from natural rubber).

Natural rubber and goods made from it have substantial shortcomings. For example, it swells greatly in oils and fats, displays little resistance

to many oxidants, particularly ozone, traces of which are always present in the atmosphere. Articles made of natural rubber have to be vulcanized, i.e., treated with sulphur at a high temperature. That is how raw rubber is converted into cured rubber or ebonite. In service, goods made of natural rubber (e.g., automobile tyres) evolve a large amount of heat which causes aging and rapid wear.

That is why scientists had to create new synthetic rubbers possessing better properties. For instance, there is a family of rubbers known as "Buna". The name is derived from the initial letters of two words "butadiene" and "natrium" (the Latin for "sodium"), sodium playing the part of the catalyst during polymerization. Some of the elastomers of this family possess excellent properties and are used mainly for the production of vehicle tyres.

Of especially great importance is butyl rubber, produced by the joint polymerization of isobutene and isoprene. First of all, it is the cheapest rubber. Secondly, in contrast to natural rubber it is almost indifferent to ozone. Besides, butyl rubber vulcanizates used extensively at present for the manufacture of tyre tubes are ten times as impervious to air as vulcanizates made of natural rubber.

Of special interest are polyurethane rubbers. They possess high tensile strength and are almost unaging. Polyurethane elastomers are used to make foam rubber for upholstery.

Rubbers have been developed in recent years which scientists could not even dream of before. These are primarily elastomers based on organo-



silicon and fluorocarbon compounds. The thermal stability of these elastomers is twice as high as that of natural rubber. They are resistant to ozone, and rubber based on fluorocarbon compounds resists even fuming sulphuric and nitric acids.

But this is not all. A recent addition are the carboxyl-containing rubbers, copolymers of butadiene and organic acids. They have a very high tensile strength.

It is thus evident that in this field too nature has yielded its superiority to man-made materials.

### **An Adamantine Heart and the Hide of a Rhinoceros**

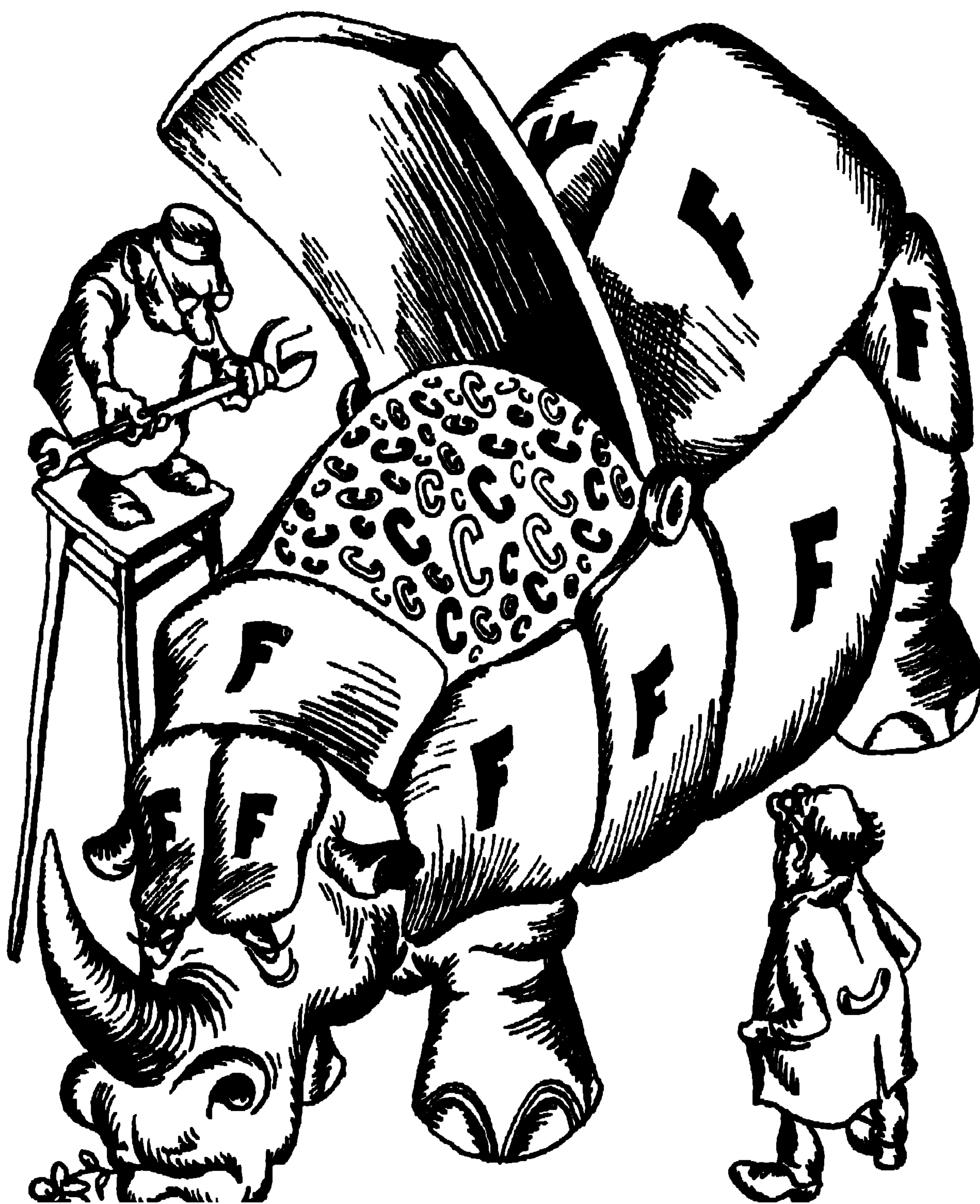
There is a class of compounds in organic chemistry called hydrocarbons. And that is just what they are, because their molecules contain hydrogen and carbon atoms, and nothing else. Their best known typical representatives are methane (constituting about 95 per cent of natural gas) and petroleum, from which various grades of petrol, lubricants, and many other valuable products are made.

Take the simplest hydrocarbon, methane  $\text{CH}_4$ . Now if we replace the hydrogen atoms in methane by oxygen atoms, what do we get? Carbon dioxide  $\text{CO}_2$ . And if we replace them by sulphur atoms? A volatile poisonous liquid called carbon disulphide  $\text{CS}_2$ . If we replace all the hydrogen atoms by chlorine atoms, we also get a well-known substance, carbon tetrachloride. But what if we take fluorine instead of chlorine?

About three decades ago hardly anybody could

answer this question intelligibly. But in our time the chemistry of fluorocarbon compounds is already an independent branch of chemistry.

In physical properties fluorocarbons are almost complete analogues of hydrocarbons. But that is as far as their common properties go. In contrast to hydrocarbons, fluorocarbons are very unreactive substances. Besides, they are very resistant



to heat. That is why they are sometimes called substances with "an adamantine heart and the hide of a rhinoceros."

The chemical explanation for their stability compared to hydrocarbons (and other classes of organic compounds as well) is relatively simple. Fluorine atoms are much larger than hydrogen atoms and therefore render the carbon atoms they surround inaccessible to other reactive atoms.

On the other hand, fluorine atoms transformed into ions are very reluctant to yield their electrons and "dislike" to react with any other atoms. Fluorine, as we know, is the most active nonmetal, and there is practically no other nonmetal which can oxidize its ion (i. e., remove an electron from it). Again, the carbon-carbon bond is itself very stable (remember diamond).

Owing to their inertness fluorocarbons have found a wide range of applications. For instance, fluorocarbon resins called Teflon can withstand heating to 300°C and are indifferent to sulphuric, nitric, hydrochloric and other acids. They resist boiling alkalis and are insoluble in all known organic and inorganic solvents.

Not for nothing are fluoroplastics sometimes called "organic platinum": they are splendid materials for making chemical laboratory ware, various industrial chemical equipment, and pipes for a great variety of purposes. Believe us, very many things in this world would be made of platinum, were it not so expensive, but fluoroplastics are comparatively cheap.

Fluoroplastics are the most slippery substances in the world. A fluoroplastic film thrown on a table will literally "flow off" it on to the floor.

Bearings made of fluoroplastics require practically no lubrication. Finally, fluoroplastics are excellent dielectrics and very heat-resistant ones too. Fluoroplastic insulation can withstand heating to  $400^{\circ}\text{C}$ , which is above the melting point of lead!

Such are fluoroplastics, which are among the most remarkable man-made materials.

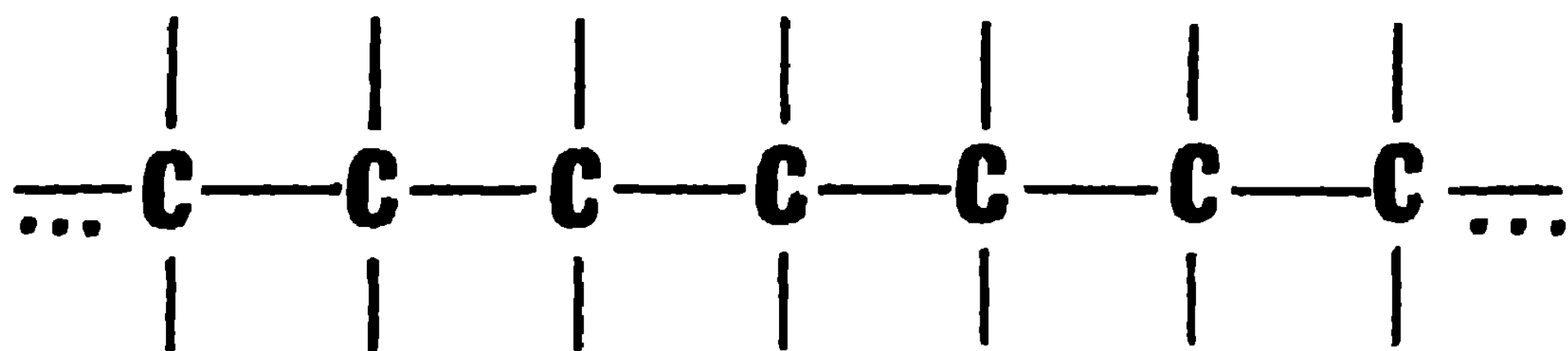
Liquid fluorocarbons are noncombustible and freeze at very low temperatures. These compounds are not attacked by fungi or insects, and are very resistant to corrosion.

### **Union of Carbon and Silicon**

There are two elements in nature which can claim a special position. The first is carbon. It is the basis of all animate things. Its claim is valid primarily because carbon atoms are capable of



combining strongly with one another to form chain-like compounds:

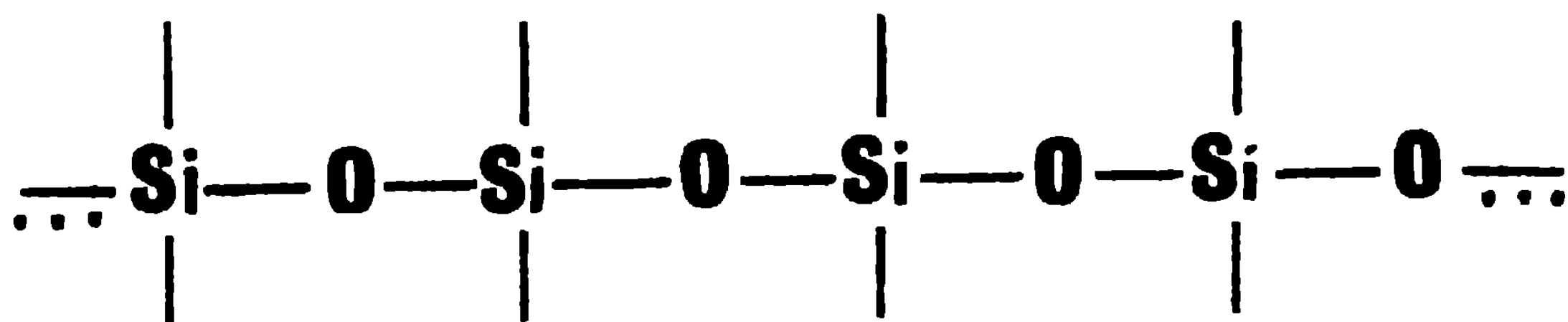


The second is silicon. It is the basis of all inorganic nature. But silicon atoms cannot form such long chains as carbon atoms, and besides the number of silicon compounds found in nature is smaller than the number of carbon compounds, though they are much more numerous than the compounds of any other chemical element.

Scientists decided to "correct" this shortcoming of silicon. Indeed, silicon is tetravalent just like carbon. True, the bond between carbon atoms is much stronger than that between silicon atoms, but silicon makes up for this by being less active.

Now if we could obtain compounds similar to organic compounds but with silicon instead of carbon, what wonderful properties they might possess!

At the beginning the scientists were unlucky. True enough, they proved that silicon could form compounds in which its atoms alternate with oxygen atoms:



but these compounds were not stable.

They scored their first success when they decided to combine silicon atoms with carbon atoms. Such compounds, which have become known as organosilicon compounds or silicones, indeed have a number of unique properties. Various resins have been made on the basis of silicones, and from them plastics can be obtained which can resist high temperatures over long periods.

Elastomers, based on organosilicon polymers possess very valuable qualities, one of which is heat resistance. Some grades of silicone rubber are stable up to 350°C. Now imagine a tyre cover made of such a rubber.

Silicone rubbers do not swell at all in organic solvents. They are now used for making various kinds of hose for fuel transport lines.

Some silicone liquids and resins hardly change their viscosity over a wide range of temperatures. This made them eligible as lubricants. Owing to their low volatility and high boiling point silicone liquids have found extensive usage in high-vacuum pumps.

Organosilicon compounds are water-repellant and this valuable property is utilized in the manufacture of water-repellant fabrics. But that is not all. Water is said to wear away stone. Tests made at important construction projects have shown that it is useful to impregnate structural materials with various organosilicon liquids.

Strong heat-resistant enamels have been developed recently, based on silicones. Copper or iron plates coated with such enamels can withstand several hours' heating at 800°C.

And this is only the beginning of the peculiar union of carbon and silicon. But this "dual" uni-



on no longer satisfies chemists. They have set themselves the task of introducing other elements into the molecules of organosilicon compounds, such as aluminium, titanium, or boron. This problem has also been successfully solved and has resulted in an absolutely new class of substances known as polyorganometallosiloxanes. The chains of these polymers may consist of different kinds of links: silicon-oxygen-aluminium, silicon-oxygen-titanium, silicon-oxygen-boron, etc. Such substances melt at temperatures of 500-600°C, competing in this respect with many metals and alloys.

There was a flash report not so long ago that Japanese scientists had allegedly succeeded in creating a polymeric material which could resist heating to 2000°C. Maybe this was an error, but even so it was not far from reality. For the term "heat-resistant polymers" will soon go down in the long list of up-to-date engineering materials.

### **Remarkable Sieves**

These sieves are of quite a singular construction. They are immense organic molecules possessing a number of interesting properties. First, like many other plastics, they are insoluble in water and organic solvents. Secondly, they consist of what is known as ionogenic groups, i.e., groups capable of producing different kinds of ions in a solvent (water, in particular). These compounds may therefore be classed as electrolytes.

The hydrogen ion in them can be replaced by some metal, a process known as ion exchange.

Accordingly, these unique compounds are

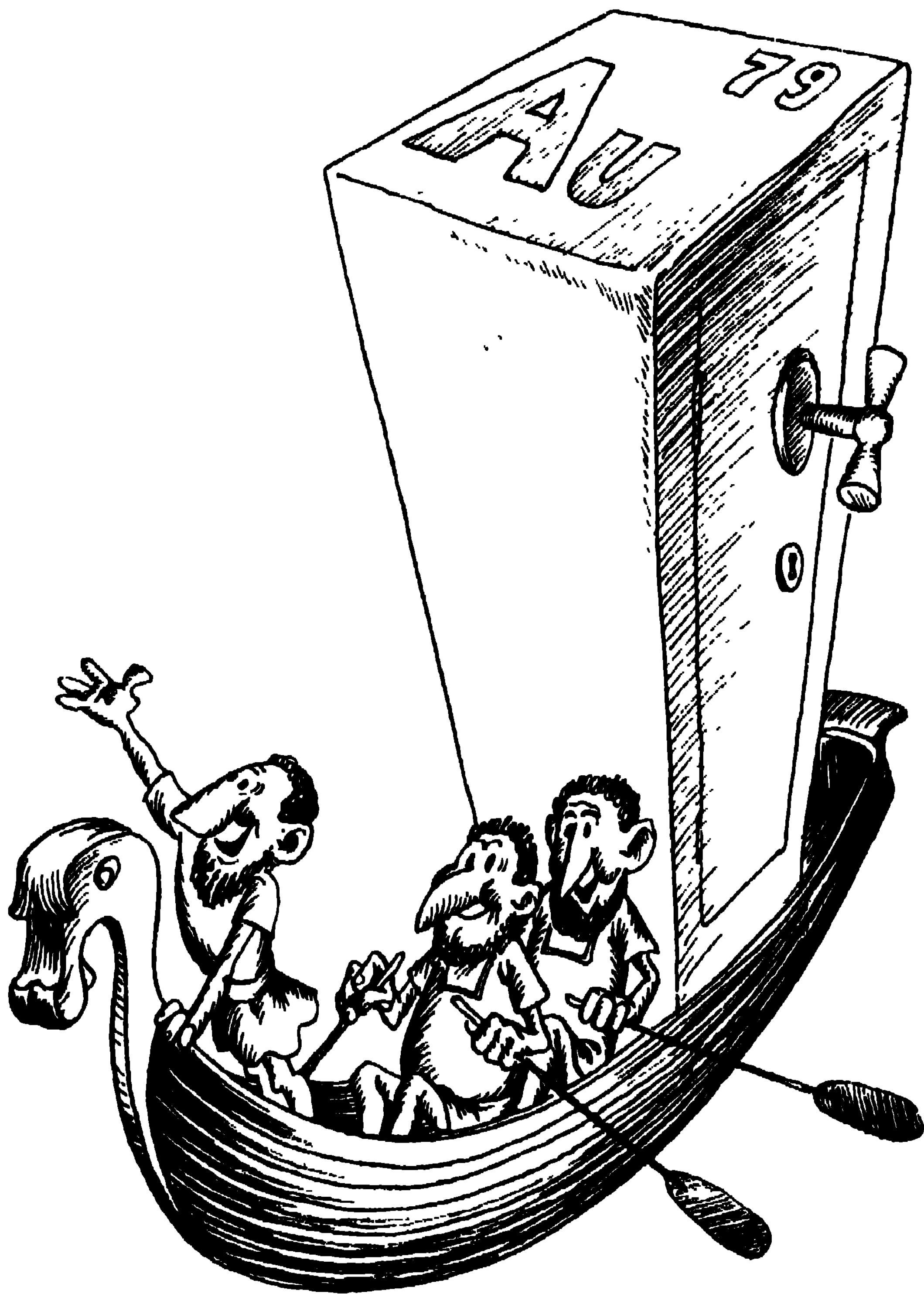


known as ion exchangers. Those capable of interacting with cations (positively charged ions) are called cation exchangers, and those which interact with negatively charged ions are called anion exchangers. The first organic ion exchangers were synthesized in the middle thirties of our century and immediately gained wide recognition. This is not surprising, because with the aid of ion exchangers hard water can be made soft and salt water fresh.

Imagine two columns, one filled with a cation exchanger and the other with an anion exchanger. Suppose we want to purify water containing common salt. We first pass the water through the cation exchanger. In it all the sodium ions are replaced by hydrogen ions, so that instead of sodium chloride our water will now contain hydrochloric acid. Then we pass the water through the anion exchanger. If it is in hydroxyl form (i.e., the anions in it capable of exchanging are hydroxyl ions) all the chloride ions in the solution will be replaced by hydroxyl ions. And the hydroxyl ions immediately form water molecules with the free hydrogen ions. Water which originally contained sodium chloride can be completely demineralized by passing it through ion-exchange columns. The product is not inferior in properties to the best grades of distilled water.

But the demineralization of water is not the only thing that made ion exchangers widely known. It was found that ion exchangers retain different ions at different strengths. Lithium ions are held more fastly than hydrogen ions, potassium ions, more fastly than those of sodium, rubidium ions, more fastly than those of

potassium, etc. Ion exchangers offered an easy way of separating metals. At present ion exchangers play an important part in various branches of industry. For example, for a long time photographic laboratories had no suitable method of



collecting precious silver from their wastes. This important problem was solved with the aid of ion-exchange filters.

Well, and will man ever be able to use ion exchangers for extracting valuable metals from sea water? The answer is yes. And though sea water contains a large amount of different salts, the recovery of the noble metals from it is evidently a thing of the near future.

Just now the difficulty is that when sea water is passed through the cation exchanger the salts contained in it virtually prevent the small amount of valuable metals from depositing on the cation exchanger. However, recently resins of a new type known as electron-exchange resins were synthesized. These not only exchange their ions for the metal ions in the solution, but also reduce the metal by donating electrons to it. Recent tests have shown that if a solution containing silver is passed through such resins, metallic silver, rather than silver ion, soon begins to deposit on the resin, and the properties of the latter persist for a considerable length of time. Thus, if a mixture of salts is passed through the electron exchanger the ions which are reduced the most readily can be converted into atoms of a pure metal.

### **Chemical Pincers**

According to an old joke there is nothing simpler than catching lions in a desert. Since the desert consists of sand and lions all you have to do is to take a sieve and sift the desert through it. The sand will pass through the apertures leaving the lions on the sieve.

But what is to be done if a valuable chemical element is mixed with a large amount of others which are of no use? Or if a harmful impurity has to be removed from a substance which contains a very small quantity of it?



This problem is not a rare one. The amount of hafnium contained in zirconium to be used for the construction of nuclear reactors must not exceed a few ten-thousandths of a per cent, whereas its content in ordinary zirconium is about two-tenths of a per cent.

Hafnium and zirconium are very close in chemical properties so that ordinary methods are useless. Even the remarkable chemical sieve we were just talking about is powerless. Still the zirconium has to be very pure. . .

For ages chemists have followed the simple formula: "Like dissolves in like." Inorganic substances dissolve readily in inorganic solvents, and organic substances in organic solvents. Many salts of mineral acids dissolve well in water, anhydrous fluoric acid, liquid hydrocyanic (prussic) acid. Very many organic substances are fairly readily soluble in the organic solvents benzene, acetone, chloroform, carbon disulphide and others.

But what about a substance intermediate between organic and inorganic compounds, how would it behave? Chemists knew of such compounds, more or less. For example, chlorophyll (the colouring matter of green leaves) is an organic compound containing magnesium atoms. It dissolves well in many organic solvents. A large number of organometallic compounds which are unknown in nature have been synthesized artificially. Many of them are soluble in organic solvents, their solubility depending on the metal they contain.

Chemists decided to take advantage of this.

During the operation of nuclear reactors it becomes necessary from time to time to replace spent uranium slugs, though the quantity of impurities (uranium fission fragments) in them is usually not more than a thousandth of a per cent. The slugs are first dissolved in nitric acid. All the uranium and other metals formed as a result of the nuclear transformations pass into nitrates. Some of the impurities, such as xenon and iodine come out automatically as gases or vapours. Others, such as tin, remain in the sludge.

Still, apart from uranium, the resulting solution contains many impurities, particularly, plutonium, neptunium, the rare-earth metals, technetium and some others. Now this is where organic substances come in. The impure nitric acid solution of uranium is mixed with a solution of an organic substance called tributyl phosphate. Practically all the uranium passes into the organic phase while the impurities remain in the nitric acid solution.

This process is called extraction. After a two-fold extraction the uranium is almost entirely free from impurities and can again be used to make uranium slugs. The impurities thus extracted are then separated to recover the most important of them, particularly plutonium and certain other radioactive isotopes.

Zirconium and hafnium can be separated in a similar way.

Extraction is now widely used in engineering. It is employed for purifying not only inorganic compounds, but many organic ones as well, notably, vitamins, fats, and alkaloids.



## **Chemistry in a White Smock**

He bore the pompous name of Johann Bombastus Theophrastus Paracelsus von Hohenheim. Paracelsus was not his surname but a nickname meaning "better than Celsus." Paracelsus was an excellent chemist and rumoured to be a wizard at healing, because he was not only a chemist but a physician as well.

The union between chemistry and medicine consolidated in the middle ages. Chemistry had not yet won the right to be called a science. Its views were too vague and its efforts disseminated in the vain search for the notorious philosopher's stone.

But while floundering in the meshes of mysticism chemists learnt to cure serious ailments. So was born iatrochemistry, or medical chemistry. In the sixteenth, seventeenth and eighteenth centuries many chemists were called apothecaries, or pharmacutists, though what they did in preparing various curatives was pure chemistry. True, they prepared them by hit-or-miss methods, and their "medicines" were not always beneficial to the patient.

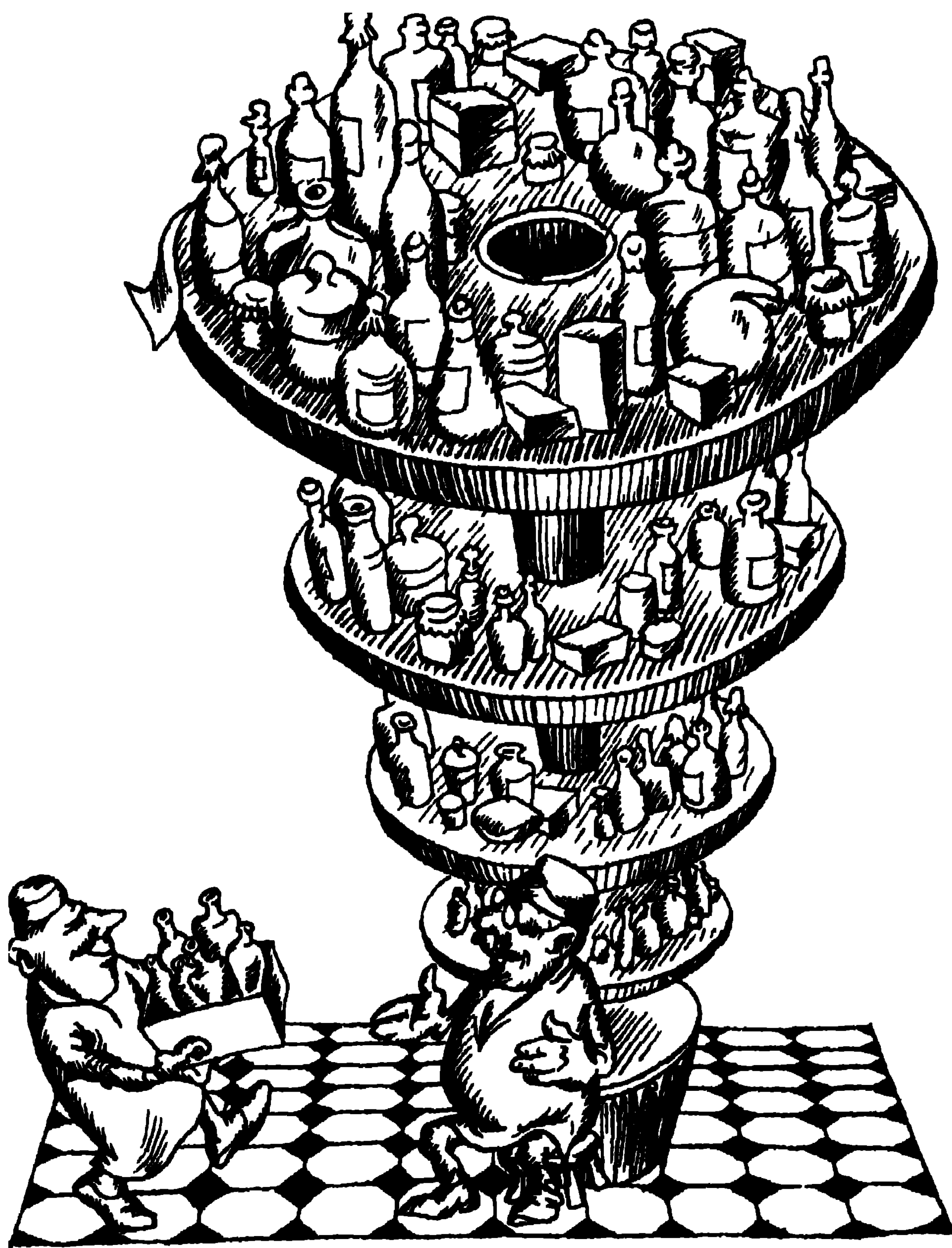
Paracelsus was one of the most prominent "pharmacutists". The list of his medicines included mercurial and sulphur ointments (used to this day, incidentally, for treating skin diseases), iron and antimony salts, and various plant juices.

At first chemistry could supply physicians only with substances found in nature and the assortment was very limited. But medicine could not content itself with this.

Looking through a modern prescription hand-



book we find that only 25 per cent of the medicines are what we would call natural preparations. They include extracts, infusions, and decoctions prepared from various plants. All the rest are synthetic medicinals unknown to nature, substances created by the might of chemistry.



The first synthetic medicinal was prepared about 100 years ago. The curative properties of salicylic acid for rheumatism had been known of long before. But it was very difficult and expensive to prepare from vegetable raw materials. Only in 1874 was a simple method developed for preparing salicylic acid from phenol.

This acid now forms the basis of many medicinal preparations, one of the best known being aspirin. As a rule the "lifetime" of a medicine is rather short: old medicines are replaced by new ones, more perfect and better adapted to cure various ailments. Aspirin is a curious exception in this respect. It discloses new, previously unknown remarkable properties each year. Aspirin can no longer be regarded merely as a febrifuge and analgesic: its range of applications is much wider.

Another very "old" medicine known to everybody is pyramidon (date of birth 1896).

Nowadays chemists synthesize several new medicines each day, medicines with a great variety of properties for curing all kinds of diseases. They range from pain-relievers to curatives for psychic diseases.

To cure people—no task could be nobler for chemists, but no task could be more difficult.

For several years the German chemist Paul Ehrlich attempted to synthesize a curative for a terrible ailment known as sleeping sickness. Each synthesis achieved something, but left Ehrlich dissatisfied. Only in the 606th attempt was he successful in obtaining an effective remedy, which he called salvarsan, and tens of thousands of people were able to get cured not only from sleeping sickness, but also from another insidious

disease, syphilis And in his 914th attempt Ehrlich obtained a still more powerful medicine called "neosalvarsan"

A medicine has to go a long way from the flask to the druggists' counter. Such is the law of doctoring that until a medicine has been checked and rechecked from all aspects it must not be recommended for use. Failure to follow this rule may lead to tragic mishaps. Not long ago a West German pharmaceutical firm advertized a new soporific called thalidomide, a tiny white tablet which could plunge a person rapidly into a deep sleep, though he suffered from stable insomnia. Thalidomide was praised to the skies but it turned out to be a terrible enemy to unborn babies. Tens of thousands of freaks—such was the price paid for putting a medicine on sale without carefully checking it.

That is why it is important for chemists and physicians to know not only that a certain medicine can cure such and such a disease, but to have a good idea of how it works, of the fine chemical mechanism of its struggle with the disease

Here is a little example The derivatives of what is known as barbituric acid are not infrequently used at present as soporifics. This acid is a compound of carbon, hydrogen, nitrogen and oxygen atoms. Besides, one of its carbon atoms has two alkyl groups attached to it, these being hydrocarbon molecules deprived of one of their hydrogen atoms. Now chemists have found that barbituric acid is soporific only if it has not less than four carbon atoms in its alkyl groups, and that the larger the number of these carbon atoms

the longer and more rapid is the action of the preparation.

The deeper scientists penetrate into the nature of diseases, the more thorough the investigations carried out by chemists. And pharmacology, whose task was formerly only to prepare various medicines and to recommend their use for various diseases, is now becoming more and more an exact science. The present-day pharmacologist must be chemist, biologist, physician and biochemist all in one, so that no thalidomide tragedies should ever occur again.

The synthesis of medicinals is one of the main achievements of chemists, the creators of a new nature.

... At the turn of our century chemists were putting a great deal of effort into the preparation of new dyes. The starting product they used was sulphanilic acid. Its molecule is very "flexible," i.e., capable of various kinds of rearrangements. And so, reasoned the chemists, under certain conditions the sulphanilic acid molecule can be transformed into the molecule of a valuable dye.

And that is exactly what happened. But until 1935 it never occurred to anyone that synthetic sulphanilic dyes were simultaneously potent medicines. The search for dyes faded into the background and chemists began to hunt for new medicinals which received the general name of sulphonamides. Some of the more common ones are: sulphapyridine, streptocid, sulphamethylthiazole, and sulphamezathine. The sulphonamides are one of the most important groups of chemical antibacterial compounds.

... South American Indians used to make a deadly arrow poison called curare from the woody vine *strychnos toxifera*. An arrow dipped in curare would cause instant death if it hit the enemy.

Why? To answer this question chemists had to get a good insight into the secret of the poison.

They found that the main active principle of curare is the alkaloid tubocurarine. When it gets into the organism, the muscles lose their ability to contract and become immobile. Respiration becomes impossible and this causes death.

However, under certain conditions this poison may be beneficial. It can be used by surgeons in carrying out certain very complicated operations. It is employed, for example, during heart operations to relax the respiratory muscles when switch-



ing the organism to artificial respiration. Thus a mortal enemy has become a friend. Tubocurarine is coming into clinical practice.

But it is still too expensive, and a cheaper and more available preparation is needed.

Once again the chemists chimed in. They studied the tubocurarine molecule from all aspects, split it in various ways and investigated the resulting "fragments." Step by step they disclosed the relation between the chemical constitution and the physiological activity of the preparation. They found that its action was due to certain groups containing positively charged nitrogen atoms, and that there must be a strictly definite distance between these groups.

Now the chemists could get down to the task of imitating nature and trying to excel it. First they obtained a preparation which was no less active than tubocurarine, and then began to improve it. The result was Syncurine, a preparation twice as active as tubocurarine.

Another vivid example has to do with malaria. The remedy for this disease used to be quinine, a natural alkaloid. But chemists were able to produce a substance sixty times as active as quinine. This substance is pamaquin, otherwise known as plasmoquine.

Present-day medicine has at its disposal an immense arsenal of remedies, one may say, for all occasions, and for almost all known diseases.

There are very potent remedies for tranquilizing the nervous system, which calm down even the most irritated person. There is a preparation which completely eliminates fright. Of course, it



would be useless to a student in fear of taking his examination.

There is a whole group of medicines known as sedatives which allay irritation. One of them is reserpine, used at one time extensively for treating certain psychic disorders (schizophrenia). Chemotherapy is now the cardinal method of treating mental disorders.

But not always have the achievements of medicinal chemistry born only positive fruit. There is, for instance, such an ominous (one could hardly call it anything else) remedy as LSD-25.

In many capitalist countries it is used as a narcotic which artificially causes the very symptoms of schizophrenia (all kinds of hallucinations enabling one to forget for a time the "difficulties of life"). But there have been no few cases where people who took LSD-25 tablets never regained their normal state.

According to present-day statistics the majority of deaths in the world are due to myocardial infarctions (heart strokes) or cerebral apoplexy. Chemists are helping to fight these maladies by inventing various cardiacs and medicines for expanding cerebral vessels.

Thanks to tubazid and para-aminosalicylic acid (PASA), two more medicines synthesized by chemists, physicians can now conquer tuberculosis in the great majority of cases.

Finally, scientists are putting great efforts into the search for remedies for cancer, this awful scourge of the human race. There are still very many obscurities in this field and it offers much room for investigation.

Physicians await new miraculous substances to



be provided by chemists. Nor do they await them in vain there is no doubt that in this field chemistry will make as good a show as elsewhere

### **A Miracle from Mould**

This word was known long ago to physicians and microbiologists, and was mentioned in special books. But until fairly recently it meant absolutely nothing to anyone not connected with biology or medicine. Nor did many chemists know its meaning. Now everybody knows it. The word is "antibiotics."

But before the layman came to know the word "antibiotics," he learnt the word "microbes." It was established that a number of diseases such as pneumonia, meningitis, dysentery, typhus, tuberculosis and others, are due to microorganisms. Antibiotics were needed to fight these microorganisms.

The curative action of some kind of moulds was known as far back as the Middle Ages. True, the ideas of the medieval Aesculapii were rather peculiar. For instance, it was thought that the only kind of mould that helped in curing diseases was that taken from the skulls of men hanged or executed for a crime.

But this is of no great significance. What does matter is that the British chemist Alexander Fleming was successful in isolating the active principle from a species of fungus mould he was studying. This resulted in penicillin, the first antibiotic.

Penicillin proved to be an excellent weapon in the fight against pathological microorganisms: streptococci, staphylococci, etc. It even vanquishes

the *Spirochaeta pallida*, the microbe that causes syphilis.

But though Alexander Fleming discovered penicillin in 1928 its formula was established only in 1945. By 1947 penicillin had been fully synthesized in the laboratory. It seemed that man had finally caught up with nature. But this was not quite so. The laboratory synthesis of penicillin is no simple thing; it is much easier to produce it from mould.

But the chemists were not to be daunted. Here too they had their say and were able to put out a good showing. The "productivity" of the mould penicillin was usually prepared from was very low, and the scientists decided to raise its efficiency.

They found substances which, inculcated into the hereditary apparatus of the microorganism, altered its characters. Moreover, these new characters became hereditary. The result was a new strain of fungi, which produced penicillin much more actively.

The present-day assortment of antibiotics is quite impressive; streptomycin and terramycin, tetracycline and aureomycin, biomylin and erythromycin. Altogether about one thousand different antibiotics are known today and around one hundred of them are used for treating different maladies. Chemistry plays a major part in their preparation.

After the microbiologists have accumulated what is known as the liquid culture medium containing colonies of microorganisms, the chemists take over.

It is their task to isolate the antibiotics, the

“active principle.” Various chemical methods are employed for extracting complex organic compounds from natural “raw materials.” The antibiotics are taken up by special absorbents. Investigators use “chemical pincers,” i.e., extract the antibiotics by means of various solvents. They purify them with ion-exchange resins, and precipitate them from solutions. This results in a raw antibiotic which is then subjected to a lengthy cycle of refining operations until it finally becomes a pure crystalline substance.

Some of them, such as penicillin, are still synthesized with the aid of microorganisms. But the production of others is only half due to nature.

But there are antibiotics, such as synthomycin, which chemists produce without the aid of nature at all. Such preparations are synthesized from beginning to end at chemical plants.

Without the powerful methods of chemistry the word “antibiotic” could never have become so widely known, nor would the veritable revolution in medicine, caused by these antibiotics, ever have happened.

### **Microelements, the Vitamins of Plants**

The word “element” has many meanings. For example, it may mean atoms of one species having the same nuclear charge. But what are “microelements”? That is what we call chemical elements contained in animal and plant organisms in very small quantities. The human organism contains 65% of oxygen, about 18% of carbon, and 10% of hydrogen. These are macroelements, since they are present in large quantities. But

titanium and aluminium may be called microelements because their content is only a thousandth of a per cent each.

At the dawn of biochemistry nobody ever paid any attention to such trifles. A mere hundredth of thousandth of a per cent was really nothing to speak of, the more so that at that time such small quantities could not even be determined. As engineering and analysis methods progressed scientists began to find more and more elements in living matter. However, for a long time the role of microelements remained unknown. Even today, though chemical analysis enables determination of millionths and even hundred-millionths of a per cent of impurities in practically any sample, the importance of many microelements for the vital activities of plants and animals has not yet been established.

But there are some things that have been established. For instance, it is known that various organisms contain such elements as cobalt, boron, copper, manganese, vanadium, iodine, fluorine, molybdenum, zinc, and even... radium. Yes, radium, though in trace amounts.

Incidentally, about 70 chemical elements have been detected so far in the human organism and there are grounds to believe that the human body contains the whole Periodic System. Moreover, each element plays a certain definite part. There is even an opinion that many disorders are due to a disturbance of the microelemental equilibrium in the organism.

Iron and manganese play an important part in plant photosynthesis. If a plant is grown in a soil not containing even traces of iron, its leaves

and stem will be white as paper. But if such a plant is sprayed with a solution of iron salts it immediately acquires its natural green colour. Copper is also needed for photosynthesis and affects the assimilability of nitrogen by plant organisms. A deficiency of copper in plants results



in poor formation of proteins of which nitrogen is a constituent.

Complex organic molybdenum compounds are constituents of various enzymes. They promote nitrogen assimilation. Molybdenum insufficiency may result in leaf blight owing to excessive accumulation of nitrates, which are not assimilated by the plants in the absence of molybdenum. Molybdenum also influences the phosphorus content in plants. In its absence inorganic phosphates do change into organic phosphates. Molybdenum insufficiency also affects the accumulation of pigments (colouring matter) in plants; the leaves become spotted and pale.

In the absence of boron plants assimilate phosphorus badly. Boron also promotes better transfer of various sugars through the plant's system.

Microelements play an important part in animal organisms too. It has been found that the complete absence of vanadium in the food of animals causes a loss of appetite and may even prove lethal. On the other hand, increasing the amount of vanadium in pigs' food results in rapid growth and in the formation of a thick layer of fat in them.

Zinc plays an important part in metabolism and is a constituent of animal erythrocytes.

When an animal (or a human being) is in a state of excitement, its liver ejects manganese, silicon, aluminium, titanium and copper into the general blood circulation cycle, but if the central nervous system is inhibited only manganese, copper, titanium are ejected, the evolution of silicon and aluminium being retarded. Besides the liver, the content of microelements in the blood



is regulated by the cerebrum, the kidneys, the lungs and the muscles.

Elucidation of the role of microelements in the growth and development of plants and animals is an important and very exciting task of chemistry and biology. Solution of this problem will doubtlessly yield substantial results in the near future and will provide science with one more path to the creation of a second nature.

### **What Plants Eat and What Chemistry Has to Do With It**

Even in ancient times there were cooks who were famed for their culinary achievements. The tables of royal palaces were heaped with all kinds of dainty dishes. Well-to-do people became particular about their food.

It would seem that plants were not so particular. Herbs and bushes have survived in hot deserts and in the polar tundra. They may be stunted and wretched to look at, but they have survived.

There was something they needed for their development, but what? Scientists sought this mysterious "something" for many years.

Despite all their experiments, in spite of all their discussions nothing definite was found.

The answer was finally supplied in the middle of the last century by the famous German chemist Justus von Liebig. He was aided by chemical analysis. He "resolved" a great variety of plants into their separate chemical elements. At the outset there were not so many of them, ten in all: carbon and hydrogen, oxygen and nitrogen,



calcium and potassium, phosphorus and sulphur, magnesium and iron. But these ten elements gave rise to the vast ocean of foliage on Earth.

It followed therefore that for plants to stay alive they had somehow to assimilate, to "eat" these elements.

But how? Where are the food stores of plants?

Obviously, in the soil, in the water, and in the air

There were some strange things, however, that had to be explained. In some soils a plant might develop rapidly, blossom, and bear fruit, whereas in others it would droop, wither and turn into a sickly freak. Evidently the latter soils lacked some element.

Even before Liebig men knew that if the same agricultural crops were sown year after year on



even the most fertile soil, harvests would become worse and worse.

The soil became impoverished. The plants gradually "ate up" all the chemical elements in it that they needed.

The soil had to be "fed", that is, the supply of substances removed from it had to be replenished. In other words, it had to be fertilized, as we usually say. Fertilizers were used way back in hoary antiquity. They were introduced into the soil intuitively, on the basis of experience handed down from generation to generation.

Liebig raised the use of fertilizers to the rank of a science and this science was named agro-chemistry. Chemistry became servant to plant growing. It was confronted with the tasks of teaching people the right way to use known fertilizers and of inventing new ones.

Dozens of different fertilizers are known today. The most important of them are potassium, nitrogenous, and phosphate fertilizers, because potassium, nitrogen and phosphorus are the elements without which not a single plant can grow.

### **A Little Analogy, or How Chemists Fed Potassium to Plants**

... There was a time when uranium, which is very well known now, dwelt in the back lanes of chemical science. Only glass staining and photography laid timid claims to it. Then radium was found in uranium. Thousands of tons of uranium ores yielded an insignificant speck of the silvery metal but the wastes containing immense quantities of uranium continued to block up

storage sites for a long time. However, uranium's hour struck at last when it proved to be the key to man's power over atomic energy. The wastes became a treasure.

... The Stassfurt salt deposits in Germany have been known since ancient times. They contained many salts, chiefly those of potassium and sodium. The sodium salt, which is table salt, immediately found usage. The potassium salts were discarded without regret and great mountains of them grew up around the mines. Nobody knew what to do with them. Though agriculture was in dire need of potassium fertilizers, the Stassfurt wastes could not be used because they contained a great deal of magnesium. Though beneficial to plants in small doses, magnesium is fatal in large amounts.

Again chemistry came to the rescue. A simple method was found for removing the magnesium from the potassium salts and the mountains around the Stassfurt mines began to disappear like snow in spring. Science historians report that the first plant for treating potassium salts was built in Germany in 1811. A year later there were already four of them and by 1872 thirty-three German plants were processing more than half a million tons of the impure salt yearly.

Potassium fertilizer plants sprang up shortly in many countries. Today the production of potassium salts in many countries exceeds their table salt output by many times.

### **The "Nitrogen Crisis"**

About one hundred years after the discovery of nitrogen a prominent microbiologist wrote: "Nitro-

gen is more valuable from the point of view of general biology than the rarest of the noble metals." And he was quite right. Nitrogen is a constituent of practically all protein molecules, whether of plant or animal origin. Without nitrogen there is no protein, and without protein there is no life. Engels said that "life is the form of existence of proteins."

To produce protein molecules plants need nitrogen. But where do they get it? The chemical activity of nitrogen is low and it does not enter into reactions under ordinary conditions. Hence, plants cannot use atmospheric nitrogen. Truly, "there's many a slip 'twixt cup and lip." Therefore, the plant's entire store of nitrogen is in the soil. Alas, this store is meagre. It holds few compounds containing nitrogen. That is why the soil loses its nitrogen rapidly and requires the addition of nitrogenous fertilizers.

The name "Chile saltpetre" has now become a thing of history. But about seventy years or so ago it was talked about everywhere.

The vast territory of the Republic of Chile includes the dismal Atacama desert which stretches over hundreds of kilometres. At first glance it is just an ordinary desert, but there is a curious thing that distinguishes it from all the other deserts of the globe: a comparatively thin layer of sand overlies thick deposits of sodium nitrate known also as sodium saltpetre. These deposits were known a long time ago, but the first time they were thought of seriously was probably when a deficiency of gunpowder began to be felt in Europe. It must be remembered that previ-

ously gunpowder was made of charcoal, sulphur and saltpetre

An expedition was sent out at short notice to fetch this overseas product. However, the entire cargo had to be thrown out into the sea. It proved that only potassium saltpetre could be used for the production of gunpowder. Sodium saltpetre absorbed moisture avidly from the atmosphere, making the gunpowder damp and useless.

That was not the first time Europeans had had to throw overseas cargoes overboard. In the seventeenth century grains of a white metal subsequently called platinum were found on the banks of the River Platino-del-Pinto. When platinum was first brought to Europe in 1735 nobody knew what to do with it. Of the noble metals only gold



and silver were known at that time, and platinum had no outlet. But some clever people noticed that the densities of platinum and gold were rather close, and making use of this fact they began to add platinum to the gold used for making coins. Now this was forgery. The Spanish government forbade any further import of platinum, and as to the reserves already accumulated in the country, they were collected and thrown out into the sea in the presence of numerous witnesses.

But the history of Chile saltpetre was not ended. It was found to be an excellent nitrogenous fertilizer which nature kindly placed at man's disposal. At that time no other nitrogenous fertilizers were known. Intensive mining operations were started at the Chilean deposits and ships loaded with the valuable fertilizer left the port of Iquique daily to deliver it to all parts of the globe.

... In 1898 Sir William Crookes's sombre prediction struck the world with awe. In one of his speeches he prognosticated death to mankind from nitrogen starvation. The fields are annually being deprived of nitrogen together with the crops, said he, and the deposits of Chile saltpetre are gradually nearing exhaustion. The treasure house of the Atacama desert was but a drop in the ocean.

It was then that scientists thought of the atmosphere. Probably the first man to draw attention to the unlimited supply of nitrogen in the atmosphere was the famous Russian scientist Timiryazev, who believed firmly in science and in the power of human genius. He did not share Crookes's misgivings. He was certain that mankind would overcome the nitrogen crisis and would find some



way out of the situation. And he was right. Not later than in 1903 two Norwegians, the scientist Kristian Birkeland and the engineer Samuel Eyde accomplished the fixation of atmospheric nitrogen on an industrial scale by means of an electric arc.

At about the same time the German chemist Fritz Haber developed a process for the production of ammonia from nitrogen and hydrogen. This finally solved the problem of combined nitrogen so necessary for plant nourishment. There is plenty of free nitrogen in the atmosphere. Scientists have calculated that if all the nitrogen in the atmosphere were transformed into fertilizers there would be enough to nourish all the plants in the world for more than a million years.

### **What is Phosphorus for?**

Justus Liebig held that a plant could absorb atmospheric nitrogen, and that the soil had to be fertilized only with potassium and phosphorus. But he was out of luck with these elements. His "patent fertilizer" which an English firm undertook to produce failed to boost harvests. Only many years later did Liebig understand and appreciate his error. He had used insoluble phosphate salts out of fear that the soluble ones would soon be washed out of the soil by rain. But it turned out that plants could not assimilate phosphorus from insoluble phosphates. And man was obliged to provide a sort of "semi-finished product" for the plants.

Each year the harvests of the world carry off about 10 million tons of phosphoric acid from the fields. What do plants need phosphorus for? It is



a constituent of neither fats nor hydrocarbons, nor do most protein molecules, especially the simplest ones, contain phosphorus. Still, without phosphorus none of these compounds would form.

Photosynthesis is not simply a process of hydrocarbon synthesis from carbon dioxide and water, which the plant can accomplish "with its little finger," it is a very complex process.

Photosynthesis takes place in what is known as the chloroplasts of the plant cells, these being special "organs" for the purpose. Chloroplasts contain a great deal of phosphorus compounds. Crudely chloroplasts can be compared to the stomach of an animal in which the food is digested and assimilated, because it is they that deal directly with the "building bricks" of the plant, namely, carbon dioxide and water.

The plant absorbs carbon dioxide from the air with the aid of phosphorus compounds. The inorganic phosphates transform the carbon dioxide into carbonate ions from which the complex organic molecules are subsequently built.

Of course, this does not exhaust the role of phosphorus in the vital activities of plants. Nor can it be said as yet that its importance for plants is wholly understood. However, even what is known already shows that the part it plays is very important.

## **Chemical Warfare**

Now this is a real war, though no cannon, tanks, rockets or bombs are used. It is a "quiet" war, often unnoticed by many, but a war to the death. And victory in this war spells happiness for all

people Does, say, the common gadfly do much harm? It has been calculated that the damage done in the Soviet Union alone by this noxious creature amounts to millions of rubles per year. And what about weeds? They cost the USA four thousand million dollars. Or take locusts; they are really a catastrophe, transforming flowering fields into bare, lifeless deserts. If we reckon up all the harm done to world agriculture by vegetable and animal robbery only in the course of a year, the sum is difficult even to imagine. The money would suffice to feed 200 million persons free of charge for a whole year!

There is a suffix "cide" which means killing. Now chemists have for some time been making all kinds of "cides." They have made insecticides which kill insects, zoocides for killing rodents, and herbicides for killing weeds. All these "cides" are now used widely in agriculture.

Prior to World War II mainly inorganic toxic chemicals were used. Various rodents, insects and weeds were killed with arsenic, sulphur, copper, barium, fluorine, and many other poisonous compounds. However, since the middle forties organic toxic chemicals have been finding ever wider application. This switchover to organic compounds was quite deliberate. They are not only less harmful to man and livestock, but are more universal and are required in much smaller quantities than inorganic chemicals to obtain the same effect. Only a millionth of a gram of DDT powder per square centimetre of ground area is enough to wipe out certain insects completely.

There are some curious facts connected with the use of organic toxic chemicals. One of the

most widely used chemicals of this class at present is hexachlorocyclohexane. But few people know that this substance was first obtained by Faraday in 1825. For more than a hundred years chemists studied hexachlorocyclohexane without even suspecting its wonderful properties. And



only after 1935, when biologists began to study it, did this insecticide begin to be put out on an industrial scale. The best insecticides known today are organophosphorus compounds, such as phosphamide or M-81.

Until recently external-action chemicals were used to protect plants and animals. However, it is easy to see that a good rain storm or a strong wind will wash or blow away these protective chemicals and they have to be applied all over again. And so scientists began to work on the problem of how to introduce the toxic chemicals into the organism being protected. The effect would be something like that of vaccination on man: a vaccinated person has nothing to fear from the disease he is vaccinated for. As soon as the microbes get into such an organism they are destroyed by invisible "health guards" which appear in it as a result of the vaccination.

It was found quite possible to prepare internal-action toxic chemicals. Scientists made use of the difference in structure of the organisms of the insect pest and the plant. Such a chemical is harmless to plants but a deathly poison to the insect.

Chemistry protects plants not only from insects, but from weeds as well. Chemicals called herbicides were invented which depress weeds but practically do not interfere with the development of the cultured plant.

Strange as it seems, the first herbicides were probably fertilizers. It was noted long ago by practical farmers that if increased amounts of superphosphates or potassium sulphate are applied to the fields the cultured plants grow intensively,

but weed growth is depressed. Now however, as with insecticides, organic compounds have become the leading herbicides.

### **The Farmer's Helpers**

The boy is just over sixteen. And here he is, probably for the first time in his life, in a perfumer's shop, not out of mere curiosity, but out of necessity. He has a moustache coming and he has come to buy shaving things.

It is quite a thrilling operation for beginners, but after about ten or fifteen years of it one sometimes prefers to grow a beard.

Grass is intolerable on a railway bed. And so people "shave it" with sickles and scythes from year to year. But take the Moscow-Khabarovsk railway. It is nine thousand kilometres long, and to cut all the grass on it (which has to be done several times each summer) almost a thousand full-time workers would be needed.

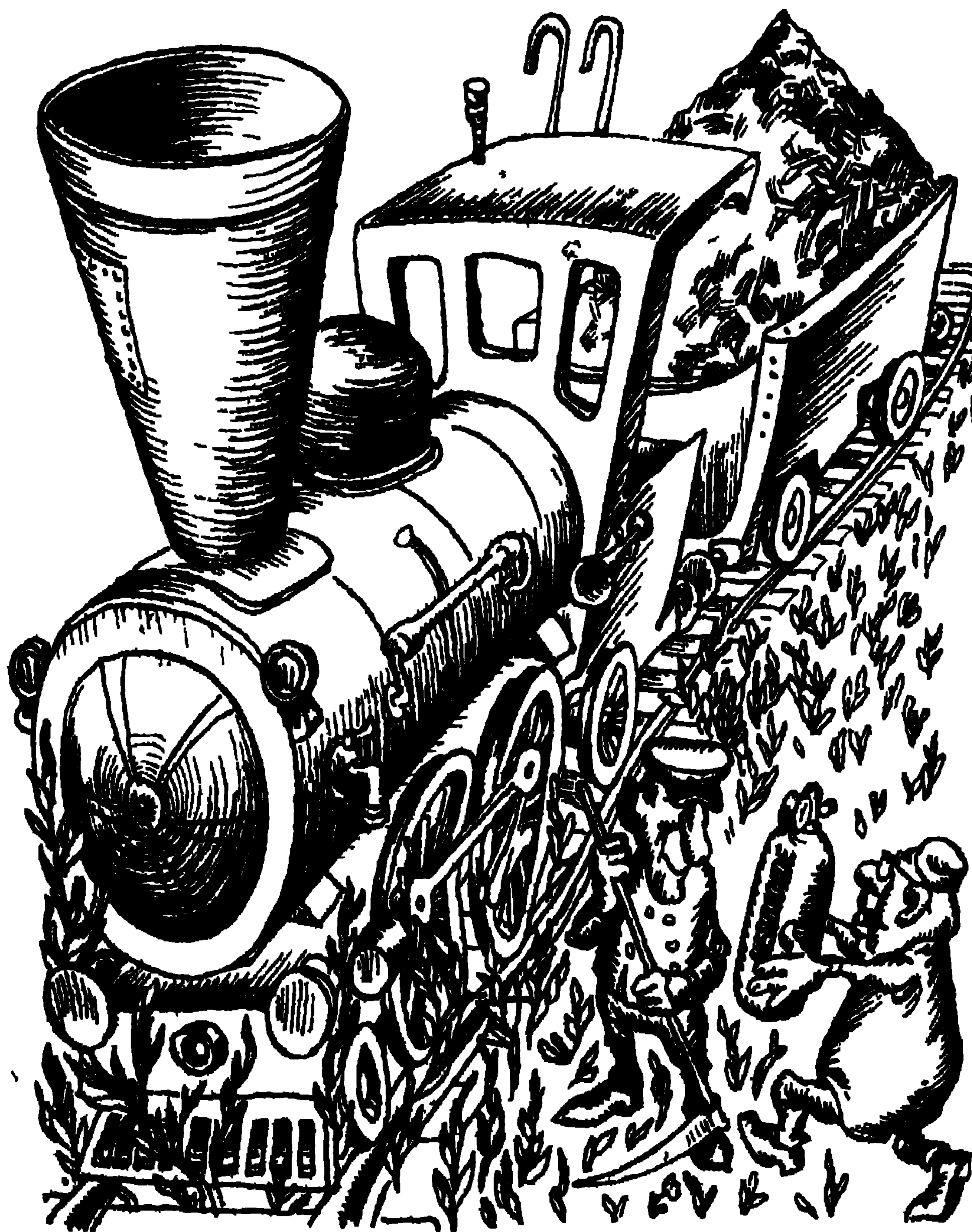
Could no chemical method of "shaving" be invented? It appears there could.

To cut the grass on one hectare 20 men have to work a whole day. Herbicides complete this operation over the same area in a few hours, wiping out the grass completely.

Do you know what defoliants are? "Folium" is the Latin for leaf. A defoliant is a chemical which makes leaves fall. The use of defoliants has made it possible to mechanize cotton harvesting. Year after year, century after century, men used to go out into the fields and pick the cotton bolls by hand. Anybody who has not witnessed manual cotton picking can hardly imagine what hard



labour it is, nor is it made any easier by having to be performed in the sun at a temperature of 40 or 50°C. Now everything is much simpler. A few days before the cotton bolls open the cotton plantation is treated with defoliants. The simplest of these is  $\text{Mg}[\text{ClO}_3]_2$ . The leaves fall off the bushes and then cotton combines come out into



the field. Incidentally, another chemical that can be used as a defoliant is  $\text{CaCN}_2$ , and the part of it that falls on the ground when the bushes are treated is a nitrogenous fertilizer to the soil.

But chemistry has gone still further in helping agriculture to "rectify" nature. Substances called auxins, which are referred to as plant hormones stimulating plant growth, have been discovered. At first only natural compounds were used for this purpose, but now chemists have learnt to synthesize the simplest of them, heteroauxin, for example, in the laboratory. These substances not only accelerate growth, blossoming and fruiting of plants, but also improve their resistance and vitality. Besides, it was found that the use of auxins in elevated concentrations has the directly opposite effect, retarding the growth and development of plants.

Here we have an almost full analogy with medicinals. There are medicines which contain arsenic, bismuth, and mercury, but in large (rather, elevated) concentrations all these substances are poisonous.

For instance, auxins can greatly lengthen the blossoming period of decorative plants, primarily, flowers. In case of sudden spring frosts they can retard the budding and blossoming of trees, and so on and so forth. On the other hand, in the cold regions where the summer is short they make it possible to grow many fruits and vegetables at accelerated rates. And though these properties of auxins have not been realized on a mass scale as yet, there is no doubt that in the near future these farmers' helpers will find extensive usage.



## **Ghosts that Serve**

Here is a fact likely to cause a sensation in the newspapers: a renowned scientist is presented by his grateful colleagues with a vase made of . . . aluminium. One should be thankful for any present, but to give an aluminium vase as a present . . . what an excellent subject for sarcasm . . . So would it be now, but a hundred years ago such a present seemed exceedingly generous. As a matter of fact, an aluminium vase actually was presented by English chemists and not just to anyone, but to D. Mendeleev himself. It was presented to him in acknowledgement of his great services to science.

See how relative everything is in this world! In the last century no cheap method of producing aluminium from its ores was known. And the metal was therefore expensive. When such a method was found, the price dropped abruptly.

Many elements of the Periodic System are far from cheap even today, which limits the range of their practical applications. But we are certain that this situation will not last. Chemistry and physics will "cut the prices" of the elements more than once. They are sure to do this because practice is drawing more and more inhabitants of the Periodic Table into the sphere of its activities.

But there are elements which either do not occur in the Earth's crust or occur in such insignificant quantities that one might say there was practically none of them. Such are astatine and francium, neptunium and plutonium, promethium and technetium . . .

However, these elements can be prepared arti-

ficially. And insofar as a chemist has a new element at his disposal he begins to think of what to do to start it on its path to life.

So far, the practically most important artificial element is plutonium. And accordingly, its world production now exceeds that of many of the "ordinary" elements of the Periodic System. It may be added that chemists class plutonium as one of the best known elements, though it is only a little over a quarter of a century "old." This is no accident, because plutonium is an excellent "fuel" for nuclear reactors, not inferior to uranium.

The energy source on some of the American Earth satellites was americium and curium. These elements are noted for very powerful radioactivity and liberate a great deal of heat when they decay. Thermocouples transformed this heat into electricity.

And what about promethium, which has not been found so far in terrestrial ores? It has gone into the manufacture of miniature batteries a little larger in size than the head of an ordinary thumb tack. The very best chemical batteries last for not more than half a year. The promethium atomic battery operates continuously for five years, and its applications range from hearing aids to guided missiles.

Astatine offers its services to physicians for fighting diseases of the thyroid gland. Attempts are now being made to cure thyroid disorders with the aid of radioactive radiations. Iodine is known to accumulate in the thyroid and astatine is the chemical analogue of iodine. Introduced into the

organism, astatine concentrates in the thyroid gland, and its radioactive properties do the rest

Thus, some of the artificial elements are by no means devoid of practical uses. True, their service to mankind is one-sided, because people can make use only of their radioactive properties. But this is only because chemists have not yet got down to their chemical properties. An exception is technetium. The salts of this metal have been found to make iron and steel articles very resistant to corrosion.

## **A Few Words of Apology**

The most difficult thing in some ventures is to stop in time.

Still, one has to stop some time, even if there is still a very entertaining story about chemistry at the tip of one's pen.

But that was only a sort of preamble. What we wanted to say in conclusion was the following.

Once we were witnesses of heated disputes, very much like those once known as the "physical versus lyrical problem". True, this time both sides in the dispute were representatives of exact sciences. One of the debaters declared that there was no such science as chemistry. It was, he contended, but a particular case of physics. That is what he said.

"There is no such science as chemistry", he went on, "because no matter what chemical process you take, you can explain its intrinsic mechanism only on the basis of physical laws. The interaction of two atoms is essentially an exchange of electrons. And what is it that makes such an exchange possible? What is chemical bonding based on? Physical laws..."

You can imagine how outraged the chemists were to hear such an opinion.

Electrons remain electrons, but the science of chemistry, this ancient but ever youthful science, does exist! It has its own rules and laws, it has its own history and boundless prospects. No matter that it often has to resort to the aid of physics, mathematics, and even cybernetics.

The peculiar feature of twentieth-century chemistry, its difference from the early periods of

its development is that it has broken up into numerous independent trends. Trends is hardly the word; rather, independent branches of science! Electrochemistry, photochemistry, radiochemistry, low-temperature and high-pressure chemistry, high-temperature and low-pressure chemistry, and so on.

And it is not uncommon that a scientist working in one of these branches finds difficulty in understanding his colleague who is a specialist in another branch. Nor is this any sign of incompetency.

Chemical "dialects" have become independent chemical "languages."

And this is only part of the trouble.

Today chemistry has become intimately interfused with other sciences: biology, geology, mechanics and cosmogony. These "alliances" have given rise to a whole pleiad of what are known as hybrid sciences: biochemistry, geochemistry, cosmochemistry, physicochemical mechanics, and many others.

Take biochemistry. It is the branch that in the long run will have to tell us what life is. In conjunction with pharmacology and medicine biochemistry will have to find ever more powerful remedies for fighting diseases.

Or cosmochemistry, the chemistry of the distant stars and planets? Though it has just come into being, in questions concerning the evolution of the universe its say will be anything but negligible.

And here something quite unexpected came to light. It is these hybrid branches that almost daily bear the most remarkable fruit. They bring

out facts, observations that nobody had ever suspected. These "hybrids" hold the greatest promise for practice.

Now try to see our side of the problem. You take a sheet of paper and want to write down something chemical. You write a phrase or two and lo, suddenly a couple of new faces are grinning up at you, the faces of physics and biology. And immediately your once perfectly clear idea becomes vague and hazy. Remember how in the tea party in "Alice in Wonderland" the Mad Hatter asked Alice the riddle: "Why is a raven like a writing desk?" Alice could not guess the answer because there was none. There is obviously no connection between ravens and writing desks. But present-day science, particularly chemistry, not infrequently finds a very definite connection between them.

If we ever have occasion in the future to write anything popular on chemistry, we shall probably use the Hatter's riddle as an epigram.

But in this book we have endeavoured to stick strictly to chemistry.

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